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FODDER-BEET

COMPARISON OF DANISH FODDER-BEET AND ENGLISH MANGOLD IN THE SOUTH OF ENGLAND, 1947–9

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In recent years a substantial proportion of the acreage devoted to the growing of roots for cattle in the countries of northern Europe has been sown with fodder-beets; e.g. in Denmark the percentage of mangolds in the root area decreased from 95 per cent. to 26 per cent. between 1931 and 1949, and that of the area of fodder-beet increased from 5 per cent. to 74 per cent. [1]. Investigations in Sweden have shown that fodder-beet is superior to swedes in yield of dry matter [2], the difference being considerable if the yield of tops is also included. It is admitted in Denmark that roots are a very expensive crop but they produce twice as many crop units[1] per acre as do grain or grass crops [3]. Under British conditions in small-scale trials at Wye, yields of 18·8 and 22·2 tons per acre of beet with 20 per cent. of dry matter have been reported [4]. Satisfactory yields of beet and dry matter have also been obtained in Scottish trials [5].

The possible value of the tops of the beet should not be overlooked. Rayns [6] has estimated that a 10-ton crop of sugar-beet produces tops yielding sufficient protein for the maintenance and production ration of a heavy-yielding cow for the whole winter.

In spite of the high costs of growing any root-crop at the present time it was considered worth while to investigate further the potentialities of fodder-beet under south of England conditions.

Preliminary trial in 1947.—In the first year of the trials it was decided to lay down large observation plots to give a guide to the chief characteristics of the beet. Four varieties of mangold were grown, Yellow Globe, Mammoth Long Red, Kirsches Ideal, and a Sugar Mangold; and two Danish beet, a fodder sugar-beet, Pajbjerg Rex IX, and a sugar-beet selected for feeding of the Øtofte type. (These will be referred to briefly as Pajbjerg Rex and Øtofte beet throughout the paper.)

The roots were grown in large non-replicated observation plots on a field with a light to medium free-working soil to which had been applied 15 tons of farmyard manure (f.y.m.) and a balanced fertilizer dressing. Each variety was sown at the rate of 8 lb. of seed per acre in rows 25 in. apart on May 17. The plants were singled on June 24 and the crop was not top-dressed.

The roots were harvested between November 6 and 14 after a very dry growing-season. The entire yield of each plot was weighed immediately after pulling, and sample roots were selected at random for the estimation of their dirt-tare and dry-matter content. Details of

[1] A crop unit is used to express the value of any particular crop in feeding livestock and is stated as equivalent to 100 kg. of barley.

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the yield, dirt-tare, and dry-matter content of the roots are given in Table 1.

TABLE 1. *Details of Yield and Dry Matter of Mangolds and Beet grown in 1947*

Variety	*Yield of cleaned roots (tons/acre)*	*Dirt-tare* (%)*	*Dry-matter content of root (%)*	*Weight of dry matter (tons/acre)*
Mangolds:				
Yellow Globe . .	27·5	0·8	13·2	3·63
Kirsches Ideal . .	22·9	4·2	14·9	3·41
Mammoth Long Red .	20·9	5·3	13·6	2·84
Sugar Mangold . .	19·1	4·4	16·1	3·08
Fodder-beet:				
Øtofte	15·1	8·8	23·3	3·52
Pajbjerg Rex . . .	15·0	13·2	23·1	3·47

* i.e. $\frac{\text{Wt. of soil on roots} \times 100}{\text{Wt. of cleaned roots} + \text{wt. of soil}}$.

The unusually low yields and high dry-matter contents of all the roots are attributable to the severe drought conditions during the summer months. In general, the yield of roots was in inverse proportion to their dry-matter content, so that both beets and mangolds (except the Mammoth Long Red) produced approximately the same weight of dry matter per acre. The chemical composition of the dry matter of the roots and the percentage of sugar in the fresh sample are given in Table 2. Of particular interest is the high percentage of sugar in the fresh roots of the beet.

A comparison of the time required to pull the same area of the different varieties showed that the Yellow Globe and Sugar Mangold were the quickest and easiest to lift, the two beets and the Mammoth Long Red were the hardest, whilst the Kirsches Ideal occupied an intermediate position. The beets had not been loosened in the ground by ploughing.

The percentage dirt-tare of the beets was higher than that of the mangolds (Table 1), although to view this figure in its true perspective the relative yields of the different varieties must also be considered.

Replicated Trials in 1948 and 1949

The same two varieties of fodder-beet were used in both the 1948 and 1949 trials with the Yellow Globe mangold as a control. The three varieties grown were, therefore, as follows:

Mangold: Yellow Globe.

Fodder-beet: Danish sugar-beet Øtofte for feeding purposes. Fodder sugar-beet, Pajbjerg Rex IX.

In both seasons a randomized block layout was employed, the four blocks each containing six sub-plots. The plots of each variety were

subdivided by lot into two sub-plots ($\frac{1}{5}$ acre in 1948 and $\frac{1}{20}$ acre in 1949) one of which received a dressing of 6 cwt. per acre of sulphate of ammonia and the other no top-dressing. There were thus six experimental 'treatments', i.e. three varieties of roots either with or without a nitrogenous top-dressing.

For the trial in 1948 a similar area of land was used as in 1947; in 1949 a field with a slightly heavier soil was used. The soil in all cases was very free-draining and in good heart. Approximately 16 t. of f.y.m. per acre were applied in 1948 and 20 t. per acre in 1949. In each season 3 cwt. per acre of superphosphate was applied as a seed-bed dressing supplemented in 1949 with 1 cwt. per acre of muriate of potash. The seed of all the strains was drilled on the flat at the rate of 6–8 lb. per acre in 25 in. rows, on fine, firm and moist seed-beds. Dates of drilling were April 19 in 1948 and May 10 in 1949. (A somewhat late date for beet.) The first top-dressing was applied immediately after the plants were singled and well-established in the rows, and the second, 3–5 weeks later when the plants were almost meeting in the rows. The dates of application were June 6 and 30 in 1948 and June 20 and July 22 in 1949.

Plant populations for both the mangolds and beet were approximately 23,000 per acre. This is a low population for beet and may not be the correct one for commercial growing, but it was considered advisable to have both the beet and mangold populations the same for experimental purposes. Inter-row cultivations were carried out until as late as possible each season and the plots were maintained free from weeds.

TABLE 2. *Chemical Composition of Mangolds and Beet in 1947*

	*Dry matter, %**					*Sugar in fresh root* %
	Crude protein	*Ether-extract*	*Soluble carbohydrates*	*Crude fibre*	*Ash*	
Mangold:						
Yellow Globe	10·0	0·4	75·2	5·3	9·1	9·07
Kirsches Ideal	9·8	0·3	76·0	5·0	8·9	10·05
Mammoth Long Red	10·4	0·5	75·3	5·4	8·4	9·81
Sugar Mangold	9·7	0·5	76·9	5·4	7·5	10·36
Fodder-beet:						
Øtofte	6·4	0·3	85·2	3·8	4·3	17·01
Pajbjerg Rex	6·7	0·3	84·5	4·1	4·4	15·68

* The corresponding dry-matter contents of the fresh roots are given in Table 1.

In 1948 the plots were harvested between November 5 and 11; in 1949 harvesting was completed in one day, November 8. The tops of both the mangolds and beet were removed by cutting close to the root, no crown being left attached to the tops of the fodder-beet. Tops from sample lengths of the rows were weighed in the field as the plots were harvested.

About 1 cwt. of roots was taken as a sample from each plot by selecting roots at random in the field before the soil on the roots had been

disturbed by loading and carting. The sample roots were weighed, cleaned by hand, and reweighed to calculate the dirt-tare (see Table 1). The entire sample of cleaned roots was then fingered, thoroughly mixed, and a 1,000 gm. sub-sample dried at 90–95° C. The dried samples from replicate plots were bulked, ground, and the conventional feeding-stuffs analysis was completed for each bulked sample. Sugar determinations, also by the method prescribed in the Fertilizer and Feeding Stuffs Acts, 1932, were made on samples of fresh roots. Samples of the tops from replicate plots were bulked, chopped in a small chaff-cutter, sub-sampled, and dried. A full analysis of the tops was completed in 1948 but only crude protein was determined in 1949.

Results

The total rainfall and its distribution varied considerably in the three growing-seasons. There was a drought in 1947, 1948 was a wet season, and in 1949 there was again a very dry summer period but followed by an extremely wet October.

TABLE 3. *Yield and Dirt-tare of Roots in 1948 and 1949*

±*Nitrogenous top-dressing*	*Variety*	*1948*		*1949*	
		Yield of cleaned roots (tons/acre)	*Dirt-tare (%)*	*Yield of cleaned roots (tons/acre)*	*Dirt-tare (%)*
N+	Yellow Globe	35·44	7·9	17·79	20·8
	Øtofte . .	21·85	18·6	13·65	22·7
	Pajbjerg Rex .	24·84	12·9	11·09	21·5
N−	Yellow Globe	27·80	8·3	18·90	13·8
	Øtofte . .	20·67	16·9	13·33	17·5
	Pajbjerg Rex .	22·14	14·5	14·36	16·2
	S.E. per plot	2·61	2·1	2·71	3·8

Data for the yield and dirt-tare of the roots are given in Table 3. The large difference in yields between the two seasons must be directly due to the very different growing-conditions in the two years. In both seasons the Yellow Globe gave significantly greater fresh yields than the two strains of beet ($P<0.01$), there being no significant difference between the yields of the two beets.

The effect of the nitrogenous top-dressing in 1948 was to increase significantly the yield of mangolds ($P<0.01$), but the small increase in the yield of beet was not significant. In 1949 the nitrogen was without effect on the yield of roots: a further reflection of the severe conditions of the drought in that year.

The dirt-tare of the beets in 1948 was almost double that of the Yellow Globe mangold, whereas in 1949, owing to the sticky condition of the soil when harvesting, there was no significant difference between the three varieties. Under the 1948 conditions the nitrogen had a variable and non-significant effect upon the percentage dirt-tare, but in 1949 it resulted in a significant ($P<0.01$) increase.

TABLE 4. *Yield of Dry Matter per Acre and Dry-matter Content (per cent.) of Roots*

±*Nitrogenous top-dressing*	*Variety*	*1948*		*1949*	
		Dry matter in cleaned root (%)	*Weight of dry matter (tons/acre)*	*Dry matter in cleaned root (%)*	*Weight of dry matter (tons/acre)*
N+	Yellow Globe	12·1	4·29	9·2	1·64
	Øtofte . .	22·1	4·83	17·7	2·42
	Pajbjerg Rex .	20·2	5·02	16·7	1·85
N−	Yellow Globe	12·4	3·45	9·3	1·76
	Øtofte . .	23·6	4·88	18·0	2·40
	Pajbjerg Rex .	21·1	4·67	16·1	2·31
	S.E. per plot	0·7	0·45	0·4	0·26

The details of the dry-matter content and weight of dry matter per acre from the roots are shown in Table 4. Of note is the high dry-matter content of the beets as compared with that of the mangold; a difference evident in both the seasons. The low dry-matter content of all the roots in 1949 must be attributed to the very dry summer followed by the abnormally wet period preceding harvesting. The application of nitrogen in 1948 depressed the mean percentage of dry matter in the roots ($P<0.01$), whereas in 1949 there was no significant effect.

In 1948 the yield of dry matter per acre from both varieties of beet significantly ($P<0.01$) exceeded that from the Globe mangold. The output of dry matter in 1949 was less than half that of the preceding years, but again both the Pajbjerg Rex ($P<0.05$) and the Øtofte ($P<0.01$) yielded more than the Globe mangold. (The low production of dry matter in the 1949 season was not confined to the beet and mangolds; adjacent experimental plots of kale were similarly affected.)

The nitrogenous top-dressing significantly increased ($P<0.05$) the yield of dry matter per acre from the mangolds in 1948 but had a variable and non-significant effect on the beet. In 1949 the nitrogen actually reduced the output of dry matter per acre, but this effect was not significant ($P>0.05$).

Although the weight of tops produced on each plot was recorded, samples for drying and analysis were bulked from the four replicates, hence a portion of the results in Table 5 could not be analysed statistically. Of interest in this table is the relatively high yields of tops from the beet as compared with the mangolds, and the differential effect of the nitrogen on the mangolds and beet.

The nitrogenous top-dressing in 1948 increased the yield of mangold tops by 1·27 tons per acre and the yields of the Øtofte and Pajbjerg Rex beet by 5·82 and 4·56 tons per acre respectively. In 1949 the nitrogen effect was variable and non-significant.

Details of the chemical composition of the roots and tops, including the percentage of sugar in the fresh roots, are given in Table 6. In both seasons the proportion of soluble carbohydrates in the dry matter of

TABLE 5. *Details of Yield and Dry-matter Content of Tops of Mangolds and Beet in 1948 and 1949*

± Nitrogenous top-dressing	Variety	1948			1949		
		Yield of fresh tops (tons/acre)	Dry matter in fresh tops (%)	Weight of dry matter in tops (tons/acre)	Yield of fresh tops (tons/acre)	Dry matter in fresh tops (%)	Weight of dry matter in tops (tons/acre)
N+	Yellow Globe	3·87	13·5	0·52	4·38	12·8	0·56
	Ötofte	12·30	12·0	1·48	6·98	13·1	0·91
	Pajbjerg Rex	11·31	12·1	1·37	5·32	13·5	0·72
N−	Yellow Globe	2·60	13·2	0·34	3·91	12·1	0·47
	Ötofte	6·48	14·0	0·91	6·15	12·7	0·78
	Pajbjerg Rex	6·75	13·4	0·90	6·04	13·1	0·79
	S.E. per plot	1·00	..	..	0·83	..	..

the two varieties of beet was markedly higher than in the mangold. The fibre-content was slightly lower. The percentage of sugar in the fresh roots of the beet was approximately three times that of the mangold and averaged 14·9 per cent. in 1948. The effect of the nitrogen in the two seasons was to raise consistently the protein-content, both crude and true, of the dry matter of tops and roots. The crude-protein content of the roots, especially the mangolds, was higher in 1949 than in 1948, and the ratio of true to crude protein was greatly reduced. This increase in non-protein nitrogen was a further effect of the dry growing-season followed by the heavy rains immediately before harvesting.

The high protein-content of the tops of the beet is of interest. In 1948 almost 5 cwt. per acre of crude protein was present in the tops of the nitrogen-dressed beet, approximately double the quantity in the non-dressed plots.

As regards chemical composition of the fresh roots, the beets contain, weight for weight, more than double the amount of soluble carbohydrates, and more protein, fibre, and ash than the mangolds, with approximately the same amount of ether extract.

In the trials, all the roots were pulled and topped by hand, no plough being used to loosen the beets in the soil. Accurate measurements of the length of time required to harvest similar areas of beet and mangolds were recorded for only a few plots, but in general the beets took approximately twice as long to pull and top as did the Globe mangolds. This was due partly to the greater effort and longer time required to loosen the beet in the ground and pull it out, and partly to the extra effort required in cutting off the tops. There was little difference between the two varieties of beet, both being firmly and deeply rooted in the ground.

After harvesting, the beets were stored in small straw-covered clamps in the open until required for feeding. Little sprouting or wastage occurred in either season, and roots kept until the June after harvesting were still sound and palatable to stock.

Fodder-beet may be fed to a wide range of stock including cattle and pigs. In Denmark a ration containing from 40 to 60 lb. of beet per day is fed to dairy stock, and in a trial conducted at this Institute quantities of

TABLE 6. *Chemical Composition of Roots and Tops in 1948 and 1949*

± Nitrogenous top-dressing	Variety	% of dry matter: Crude protein	True protein	Ether-extract	Soluble Carbo-hydrates	Fibre	Ash	True as % of crude protein	Sugar in fresh root (%)
				ROOTS (1948)*					
N+	Yellow Globe	11·0	4·5	0·4	70·8	6·0	11·8	40·9	4·3
	Ötofte	7·2	3·6	0·3	79·7	4·7	8·1	50·0	14·7
	Pajbjerg Rex	7·7	3·4	0·2	80·1	4·8	7·2	44·2	14·4
N−	Yellow Globe	7·0	3·7	0·3	76·6	5·8	10·3	52·9	4·3
	Ötofte	4·9	2·9	0·2	82·9	4·8	7·2	59·2	15·7
	Pajbjerg Rex	4·9	2·8	0·3	82·3	4·9	7·6	57·1	14·8
				ROOTS (1949)*					
N+	Yellow Globe	21·5	7·3	0·6	50·3	7·2	20·4	34·0	3·7
	Ötofte	11·4	4·7	0·2	73·5	5·2	9·7	41·2	11·6
	Pajbjerg Rex	12·5	5·0	0·3	69·8	5·6	11·8	40·0	9·9
N−	Yellow Globe	20·2	6·9	0·6	53·1	6·9	19·2	34·2	3·8
	Ötofte	10·9	4·8	0·3	73·6	5·2	10·0	44·0	11·2
	Pajbjerg Rex	12·3	4·9	0·4	72·0	5·2	10·1	39·8	9·8
				TOPS (1948)					% Crude protein in D.M. of tops (1949)
N+	Yellow Globe	15·8	12·6	2·5	49·0	10·2	22·5	79·7	21·6
	Ötofte	16·4	12·1	2·7	54·0	9·7	17·2	73·8	20·9
	Pajbjerg Rex	17·2	12·9	2·5	52·7	9·7	17·9	75·0	21·5
N−	Yellow Globe	14·5	11·8	2·6	48·8	9·9	24·2	81·4	21·2
	Ötofte	13·4	10·7	2·8	50·7	10·9	22·2	79·9	19·2
	Pajbjerg Rex	14·2	11·1	3·1	54·0	9·6	19·1	78·2	20·1

* The corresponding dry-matter contents of the fresh roots are given in Tables 4 and 5.

beet up to 60 lb. per day were successfully fed to milking animals. This was considered a heavy ration, but throughout the feeding-period the normal decline in milk yield was recorded and the health and live-weight of the animals were unaffected.

Discussion

These experiments show that the fodder-beet offers certain advantages over the mangold. Under identical conditions of season, cultivation, and fertilizer treatment, the beets produced significantly larger yields of dry matter per acre than the Globe mangold, and in a much more concentrated form, the same weight of dry matter being contained in 55 lb. of fodder-beet compared with 100 lb. of mangold.

The costs per acre of growing fodder-beet and mangolds up to the time of harvesting, i.e. for seed, fertilizer, and cultivations, are about the same, but thereafter the costs of clamping, carting, cutting, and feeding are much less for beet. It must be admitted that pulling and topping is more expensive with beet than with mangolds, but, even so, this is a relatively small item of the total costs of production.

In feeding-value the roots are as valuable as mangolds for the dairy cow and more economical to feed. They are also a useful home-grown feeding-stuff for pigs [4, 7]. When fed to pigs, 5·6 lb. of fodder-beet can replace 1 lb. of meal, enabling a saving of almost 3 cwt. of meal per fattening pig. The keeping quality of the roots was excellent.

The trials have further demonstrated that the beet will produce 11–12 t. per acre of valuable tops if adequately fertilized. If not eaten this weight of tops would be no mean addition to the soil when ploughed in.

The effect of the heavy top-dressing of inorganic nitrogen has been variable. In 1948 on mangolds it resulted in significant increases in the yield of roots and their dry matter per acre with little effect on the yield of tops. On the beet the weight of dry matter was little affected although the tops showed significant increases in yield. There seems little justification for such a heavy top-dressing of nitrogen for fodder-beet. Under the more moist conditions of 1948 the recovery of nitrogen in the tops and roots of the three varieties was 65 per cent., whereas in 1949 the nitrogen was without significant effect in any direction and the recovery was negligible.

It must be remembered that fodder-beet, like sugar-beet and mangolds, is susceptible to the disease Virus Yellows, and that all the usual precautions to prevent the spread of this disease in the sugar-beet crop will be required in the fodder-beet crop.

The advantages which the fodder-beet offers when compared with mangolds argue strongly in favour of the wider use of this crop. Wherever roots are grown, and especially on the pig farm, there is a place for the fodder-beet.

Summary

1. Details are given of field trials carried out in 1947, 1948, and 1949, comparing two varieties of Danish fodder-beet with the Yellow Globe mangold, each at two levels of nitrogenous manuring.

2. In 1948, a wet year, the average yield of the cleaned beet was 22·4 t. per acre; in 1949, a dry year, 13·1 t. per acre. The average yield of the mangolds was 31·6 and 18·4 t. per acre in the two years.

3. The percentage dry-matter content of the beets averaged 21·8 per cent. in 1948 and 17·0 per cent. in 1949, as against 12·3 and 9·3 per cent. for the mangolds.

4. The beet yielded 4·85 t. of dry matter per acre in 1948 and 2·25 t. in 1949, and the mangolds 3·87 and 1·70 t. The yield of the beet tops was 6–12 t. per acre.

5. The chemical composition of the dry matter of the beet and mangolds was similar, apart from a higher soluble-carbohydrate content and lower ash-content in the beet.

6. The effect of a heavy nitrogenous top-dressing was negligible in a dry season. In a wet season statistically significant increases were recorded in the yield of mangold root and fodder-beet top.

7. The advantages of the fodder-beet, as compared with the mangolds, are discussed.

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THE ASH CONSTITUENTS OF SOME HERBAGE PLANTS AT DIFFERENT STAGES OF MATURITY

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THE simplification of seeds-mixtures, and the concentration of attention upon a limited number of grasses and clovers, has on many occasions produced swards which are more efficient in the production of dry matter than much of the older grassland. Of this there is no doubt. Evidence of simultaneous change in the qualitative character of the herbage is, however, very meagre; in particular it is remarkable that possible effects on the mineral content should have received so little attention. It would seem reasonable to suppose that the probability of deficiency or unbalance in the mineral content of a sward may be increased by limiting the number of species. This possible weakness of the modern ley has not passed unnoticed by one of its leading advocates [1].

Existing information on the ash constitution of individual herbage species, which is extremely limited, has been reviewed by us elsewhere [2, 3]. Stapledon has said that the great need is for a wider knowledge of the mineral contents of the grasses, clovers, and herbs generally, and these under widely differing conditions of soil and environment. The effect of one variable, viz. manurial treatment, on a limited number of herbage plants has already been investigated by the authors [2]. The present work relates to a wider range of species, including a number of herbs and legumes, and to the effect of a second variable, namely stage of growth.

Experimental Technique

The material for this investigation was obtained from 16 herbage species—8 grasses, 4 legumes, and 4 herbs—which were sampled at five different stages of maturity. These species were sown in the nursery of the King's College Experimental Farm at Cockle Park in the autumn of 1947, and are well established. The soil is a deep, light loam overlying a sandstone of the Carboniferous Series, and has had uniform manurial treatment for a good many years.

Five series of samples were taken during the course of the growing season, the first when the plants were in young leaf (the legumes being slightly less advanced than the grasses), the second when in late leaf, the third at the mid-flowering period, the fourth at full maturity, and the last when all species were in decline. The actual sampling was effected by cutting with shears at 1–1½ in. above ground-level, suitable precautions being taken to ensure representative samples and to avoid soil contamination.

The procedure followed in preparing the samples, and the analytical methods used, have been described elsewhere [2, 3].

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Results

Silica-free ash.—This fraction may be considered to give some indication of the all-round mineral efficiency of the plant. It will be noted that the herbs do not contain a significantly larger amount than the legumes, and that both show differences from the grasses which are very highly significant ($P = 0{\cdot}1$ per cent.), containing approximately twice as much as the latter. Chicory contains markedly higher amounts of silica-free ash (13·24 per cent.) than all other species, and has 2 per cent. more than lucerne, which takes second place. There is comparatively little variation between the grasses, only one of which, viz. Chewings fescue, has less than 4 per cent.

All species show evidence of a decline in silica-free ash as maturity is approached, 13 out of 16 plants giving a significant negative correlation with age.

Calcium.—Although the legumes, as a group, have a significantly higher mean (P = 5 per cent.) calcium-content than the herbs, both groups are rich in this element, and both contain very significantly larger amounts (P = 1 per cent.) than the grasses. Lucerne, as compared with any other herbage plant examined, is quite outstanding as a source of calcium, whilst sainfoin contains substantially less than any other member of its group. That plantain contains much calcium has emerged from earlier investigations [4, 2]; but Fagan and Watkins found it inferior in this respect to the common nettle (*Urtica dioica*). On this occasion it has proved superior to any other of the herbs examined. The grasses show comparatively little variation; it is of interest to note that one of the highest calcium-contents occurs in a less fashionable member of the group (meadow fescue), and the lowest in another fescue (Chewings fescue).

Of the 8 grasses examined, 5 show a significant negative correlation between calcium-content and age; two others showed evidence of a similar trend. The herbs and legumes provided much less consistent results. Only one herb (plantain) produced a significant correlation; yarrow appeared to show a downward trend, whilst the calcium in burnet reached maxima at the beginning and end of the season. Of the legumes, two species gave significant negative correlation and two (alsike and lucerne) showed a significant positive correlation.

Phosphorus.—There is no significance between the mean amounts of phosphorus in herbs and legumes, but both groups contain very much more than the grasses, the differences being very highly significant. The herbs and legumes considered together show comparatively little variation, chicory having the highest content and burnet the lowest. The latter herb contains little more than most of the grasses which, as a group, are no more variable than the herbs and legumes. It will be noted that Chewings fescue is a particularly poor source of phosphorus.

Six of the 8 grasses examined give a significant negative correlation, at the 5 per cent. level, between phosphorus-content and age; two just fail to attain significance but show a similar trend. In both legumes and herbs, 3 out of 4 species give significant negative correlation. Trefoil

shows the same tendency for phosphorus to fall as maturity advances, but fails to give significant correlation, whilst only three results are available for chicory. There is thus a general tendency to decline with advancing maturity.

Magnesium.—There is here the same relationship between groups as was shown to exist for phosphorus; no significant difference exists between the proportions of magnesium in legumes and herbs, but both contain very highly significantly larger amounts than do the grasses. Burnet contains much more magnesium than any species in any group, and two of the fescues, viz. tall fescue and red fescue respectively, are the best and poorest sources among the grasses.

As in the case of phosphorus, there is a general tendency for magnesium-content to decline with advancing maturity. The four herbs all give significant negative correlations, and if some of the legumes and grasses fail to do so, the trend is usually evident. No single species gives a significant positive correlation.

Sodium.—Of the three groups, the legumes are remarkably poor sources of sodium, only one, viz. trefoil, containing even a moderate proportion. Whereas two of the herbs are equally poor, plantain and chicory are outstandingly good, and contain larger amounts of this element than any other plant examined. The grasses, with the single exception of red fescue, are fairly consistent, containing amounts not less than 0·10 per cent.

The relationship of sodium-content to age appears to be different in the three groups. Three out of four legumes give a significant positive correlation. No significant correlations emerge in the case of the herbs; yarrow and burnet give evidence of having minimum amounts of sodium in mid season. The grasses in general show a declining sodium-content with advancing maturity.

Potassium.—The herbs are significantly richer than the legumes and very highly significantly richer than the grasses. Yarrow, and more particularly chicory, contain quite exceptionally large amounts of potassium. The legumes show comparatively little variation, as do the grasses.

In all groups there is a fairly well-marked tendency for the potassium-content to fall with age; 3 legumes, 1 herb, and 6 grasses give significant negative correlations.

Chlorine.—There are no significant differences between groups in respect of this element, but certain species stand out by reason either of their richness or their poverty. Chicory is an exceptional source of chlorine; sainfoin and burnet are particularly poor. As compared with the other grasses, cocksfoot is low, whilst meadow fescue is the highest of this group, and, in fact, contains more chlorine than any species except chicory.

Chlorine tends to be negatively correlated with age in both legumes and herbs. The grasses, on the other hand, show no consistency in this relationship. Five members of the last group either give a significant negative correlation or show a tendency for chlorine to decline, but with the three remaining species the converse is true.

Iron.—Both herbs and legumes prove to contain more iron than the grasses, the difference in the first case being very highly significant, and in the second, significant. The superiority of the herbs to the legumes in respect of this element is highly significant. The actual differences between the group means are not so large as the foregoing might imply, variance within the groups being small. Chicory and plantain are exceptional sources of iron, both containing nearly 500 p.p.m. Amongst the legumes, trefoil must be considered a very good source and sainfoin a relatively poor one. Timothy, with 374 p.p.m., is as good as trefoil; cocksfoot is the poorest of the grasses and, indeed, is the lowest of any species examined.

There appears to be no relationship between iron-content and stage of growth in herbs. Some evidence of decline with advancing maturity appears in the leguminous group, although only one species, viz. sainfoin, gives a significant negative correlation. Only 2 out of 8 grasses show a significant negative correlation, there being a general tendency in members of this group for iron to reach a mid-season minimum and to increase thereafter.

Manganese.—As with iron, both herbs and legumes contain much more manganese than do the grasses. The difference between the first and third of these groups is highly significant and between the second and third very highly significant. Although the legumes appear to be slightly better sources of this element than the herbs, no significance can be attached to this difference. Alsike and chicory are richer in manganese than any of the other species examined; burnet, as compared with other members of the herb and legume groups, is poor. It is perhaps noteworthy that the four fescues all contain little manganese, which seems surprising because the normal habitat of these grasses is on acid soils. Rye-grass ranks with the fescues, but cocksfoot is a comparatively good source of the element.

All members of the herb group show evidence of decline in manganese as maturity advances, 3 out of 4 species giving significant negative correlations. The grasses show a very similar seasonal trend, giving 6 out of 8 significant negative correlations. On the other hand, in only one legume, namely sainfoin, is manganese-content inversely related to maturity. Chewings fescue is alone among the 16 species in having manganese-contents significantly and positively correlated with stage of growth.

Copper.—The group means show very little variation in respect of copper, the only significant difference being that between the herbs and the grasses. Chicory would appear to be the best source of copper, whilst yarrow, plantain, alsike, red fescue, and cocksfoot must also be considered good. Tall fescue and Chewings fescue are both rather unsatisfactory, the former, in particular, possibly containing insufficient copper to meet the needs of grazing stock.

In all but one member of the herb and legume groups (alsike) there is evidence that the copper-contents decline with age. In every one of the 8 grasses there is failure to obtain a significant negative correlation-coefficient, and there is little evidence of any seasonal trend.

TABLE 1. *Ash Constituents of Herbs, Legumes, and Grasses at Different Stages of Growth (Results calculated to Dry-matter Basis)*

HERBS

Species	*Cut*	*Age in weeks*	*Silica-free ash* %	*Calcium (CaO)* %	*Phosphorus (P_2O_5)* %	*Potassium (K_2O)* %	*Magnesium (MgO)* %	*Chlorine (Cl)* %	*Sodium (Na_2O)* %	*Iron (Fe)* *p.p.m.*	*Manganese (Mn)* *p.p.m.*	*Copper (Cu)* *p.p.m.*	*Cobalt (Co)* *p.p.m.*
Yarrow (*Achillea Millefolium*)	1	0	11·23	2·01	1·14	5·13	1·19	0·63	0·08	435	67·2	13·4	0·16
	2	3	11·04	1·94	1·03	4·94	0·98	0·58	0·06	232	67·1	11·8	0·20
	3	6	9·83	1·59	0·85	4·20	0·93	0·52	0·04	304	43·2	9·3	0·19
	4	8	9·83	1·92	0·84	4·47	1·02	0·54	0·05	287	41·1	9·5	0·15
	5	12	8·11	1·57	0·69	3·39	0·75	0·37	0·08	213	22·9	9·2	0·14
		Mean	10·01	1·80	0·91	4·42	0·98	0·53	0·06	294	48·3	10·6	0·17
		Corr. coeff.	−0·97*	−0·73	−0·99*	−0·94*	−0·88*	−0·93*	−0·11	−0·72	−0·97*	−0·89*	−0·53
Burnet (*Poterium Sanguisorba*)	1	0	7·31	1·97	0·79	2·35	2·37	0·15	0·09	363	53·1	10·3	0·22
	2	3	7·19	1·72	0·77	2·53	1·94	0·16	0·06	207	41·4	9·7	0·16
	3	6	6·52	1·68	0·54	2·11	1·77	0·13	0·06	181	23·2	6·3	0·28
	4	8	6·79	1·84	0·50	2·16	1·50	0·16	0·07	174	21·3	6·4	0·11
	5	12	6·14	2·00	0·50	1·96	1·53	0·16	0·08	320	18·2	7·1	0·15
		Mean	6·79	1·84	0·62	2·22	1·82	0·15	0·07	249	31·2	8·0	0·18
		Corr. coeff.	−0·99*	+0·20	−0·89*	−0·83	−0·92*	−0·30	−0·78	−0·25	−0·94*	−0·80	−0·40
Plantain (*Plantago lanceolata*)	1	0	..	..	..	..	..	..	..	..	..	..	..
	2	3	10·85	2·61	0·84	3·10	1·12	0·67	0·40	625	60·1	15·6	0·31
	3	6	9·65	2·39	0·78	3·57	1·04	0·62	0·43	389	28·4	8·7	0·12
	4	8	9·85	2·32	0·75	3·42	1·06	0·56	0·40	471	29·6	10·8	0·19
	5	12	8·39	1·95	0·64	3·13	0·84	0·62	0·36	474	23·0	6·9	0·18
		Mean	9·69	2·32	0·75	3·31	1·01	0·62	0·40	490	35·3	10·5	0·20
		Corr. coeff.	−0·96*	−0·99*	−0·95*	−0·06	−0·95*	−0·48	−0·75	−0·48	−0·84	−0·86	−0·52
Chicory (*Cichorium Intybus*)	1	0	14·86	1·54	0·80	6·64	1·18	1·08	0·34	482	74·6	15·4	0·19
	2	3	..	..	..	..	..	..	..	..	..	..	..
	3	6	..	..	..	..	..	..	..	..	..	..	..
	4	8	13·60	2·22	1·20	4·40	1·06	1·00	0·31	536	55·8	12·2	0·23
	5	12	11·28	2·23	1·05	5·49	0·98	0·69	0·45	388	42·2	9·9	0·19
		Mean	13·24	2·00	1·11	5·51	1·07	0·92	0·37	469	57·5	12·5	0·20
		Corr. coeff.	−0·94	+0·95	+0·66	−0·70	−0·99*	−0·87	+0·60	−0·47	−0·99*	−0·99*	+0·19
Mean of herb species			9·56	1·97	0·81	3·70	1·25	0·51	0·20	358	41·8	10·2	0·19
Standard error of herb species			±0·60	±0·07	±0·05	±0·33	±0·11	±0·07	±0·04	±10	±4·4	±0·7	±0·01

* Denotes significance at 5% probability.

* Denotes significance at 5% probability.

LEGUMES

Trefoil (*Medicago lupulina*)	1	0	10·71	2·46	1·05	3·27	1·44	0·74	0·15	442	51·0	9·6	0·21
	2	3	7·29	2·60	0·77	2·92	1·37	0·63	0·21	375	45·0	7·0	0·16
	3	6	9·12	2·40	0·70	2·44	1·22	0·46	0·21	279	38·3	7·1	0·29
	4	8	8·06	2·27	0·70	2·43	1·24	0·49	0·20	445	40·4	7·4	0·15
	5	12	7·98	1·87	0·73	2·78	1·07	0·52	0·12	373	42·5	5·3	0·20
		Mean	8·63	2·32	0·79	2·77	1·27	0·56	0·18	383	43·4	7·3	0·20
		Corr. coeff.	−0·57	−0·88*	−0·85	−0·65	−0·98*	−0·79	−0·54	−0·11	−0·68	−0·88*	−0·04
Alsike (*Trifolium hybridum*)	1	0	9·57	2·57	0·99	3·06	0·97	0·52	0·04	491	60·7	12·4	0·23
	2	3	9·16	2·82	0·86	2·83	0·99	0·45	0·05	296	52·3	8·8	0·18
	3	6	..	..	..	..	..	..	..	..	..	..	..
	4	8	8·50	2·84	0·65	2·28	1·11	0·36	0·06	298	62·2	8·9	0·15
	5	12	7·87	2·92	0·54	2·19	1·10	0·33	0·07	205	59·9	12·0	0·13
		Mean	8·78	2·79	0·76	2·59	1·04	0·42	0·06	323	58·8	10·5	0·17
		Corr. coeff.	−0·99*	+0·95*	−0·99*	−0·98*	+0·93	−0·98*	+0·95*	−0·88	+0·30	−0·01	−0·88
Lucerne (*Medicago sativa*)	1	0	13·40	2·74	1·52	4·70	1·05	0·73	0·06	558	60·2	12·1	0·25
	2	3	11·46	2·60	1·03	4·03	0·92	0·58	0·07	229	29·6	11·5	0·11
	3	6	10·12	2·95	0·75	2·72	0·91	0·40	0·10	217	30·8	8·2	0·15
	4	8	10·04	3·14	0·68	2·36	0·82	0·45	0·13	234	29·4	7·0	0·14
	5	12	10·04	3·60	0·56	1·86	0·87	0·35	0·13	219	34·5	6·8	0·11
		Mean	11·01	3·01	0·91	3·13	0·91	0·50	0·10	291	36·9	9·1	0·15
		Corr. coeff.	−0·88*	+0·92*	−0·93*	−0·97*	−0·81	−0·92*	+0·95*	−0·81	−0·62	−0·93*	−0·67
Sainfoin (*Onobrychis sativa*)	1	0	8·74	1·83	1·26	4·43	1·36	0·16	0·03	360	70·3	10·4	0·24
	2	3	8·56	1·51	1·25	3·96	1·28	0·18	0·05	265	50·7	10·0	0·20
	3	6	6·07	1·36	0·73	2·74	1·09	0·13	0·06	200	40·9	7·2	0·14
	4	8	5·73	1·24	0·69	2·27	1·89	0·13	0·07	199	30·1	7·8	0·10
	5	12	4·92	1·27	0·50	1·87	0·90	0·10	0·07	131	27·5	5·0	0·12
		Mean	6·80	1·44	0·89	3·05	1·31	0·14	0·06	231	43·9	8·1	0·16
		Corr. coeff.	−0·97*	−0·89*	−0·96*	−0·99*	−0·23	−0·87	−0·88*	−0·97*	−0·95*	−0·96*	−0·89
Mean of leguminous species			8·81	2·37	0·84	2·90	1·14	0·41	0·10	306	45·1	8·70	0·17
Standard error of leguminous species			±0·47	±0·16	±0·06	±0·19	±0·06	±0·05	±0·01	±8	±3·0	±0·52	±0·01

* Denotes significance at 5% probability.

TABLE 1 (*continued*)

GRASSES

Species	*Cut*	*Age in weeks*	*Silica-free ash* %	*Calcium (CaO)* %	*Phosphorus (P_2O_5)* %	*Potassium (K_2O)* %	*Magnesium (MgO)* %	*Chlorine (Cl)* %	*Sodium (Na_2O)* %	*Iron (Fe)* *p.p.m.*	*Manganese (Mn)* *p.p.m.*	*Copper (Cu)* *p.p.m.*	*Cobalt (Co)* *p.p.m.*
Perennial ryegrass (*Lolium perenne*)	1	0	6·02	0·94	0·69	2·78	0·51	0·64	0·26	333	31·1	15·2	..
	2	3	5·67	0·84	0·72	2·71	0·34	0·53	0·18	301	22·4	7·1	0·17
	3	6	3·21	0·51	0·57	2·36	0·27	0·48	0·17	241	20·3	4·8	0·15
	4	8	4·03	0·50	0·57	2·32	0·41	0·53	0·14	181	17·9	6·5	0·15
	5	12	3·92	0·47	0·41	1·74	0·25	0·39	0·20	203	16·3	9·1	0·14
		Mean	4·57	0·65	0·59	2·38	0·35	0·51	0·19	252	21·6	8·5	0·15
		Corr. coeff.	−0·66	−0·91*	−0·94*	−0·97*	−0·72	−0·93*	−0·58	−0·90*	−0·94*	−0·41	−0·91
Cocksfoot (*Dactylis glomerata*)	1	0	6·10	0·92	0·70	3·37	0·41	0·29	0·20	321	61·3	7·0	0·20
	2	3	5·50	0·65	0·70	3·08	0·31	0·25	0·17	156	49·8	11·4	0·07
	3	6	4·81	0·46	0·64	2·66	0·33	0·33	0·17	122	47·8	7·3	0·09
	4	8	4·70	0·48	0·56	2·58	0·35	0·34	0·15	167	36·0	15·0	0·21
	5	12	4·77	0·44	0·35	2·20	0·40	0·33	0·14	232	32·5	9·1	0·11
		Mean	5·18	0·59	0·59	2·78	0·36	0·31	0·17	200	45·5	10·0	0·14
		Corr. coeff.	−0·91*	−0·88*	−0·93*	−0·99*	+0·02	+0·72	−0·94*	−0·32	−0·96*	+0·31	−0·24
Timothy (*Phleum pratense*)	1	0	..	..	..	..	..	..	..	..	..	..	..
	2	3	4·76	0·67	0·61	2·27	0·50	0·35	0·30	448	35·3	8·2	0·13
	3	6	5·52	0·63	0·53	2·80	0·42	0·51	0·39	292	34·0	6·8	0·18
	4	8	5·42	0·47	0·52	2·59	0·39	0·68	0·33	349	27·0	7·3	0·12
	5	12	4·20	0·56	0·44	2·74	0·36	0·70	0·17	408	25·3	7·6	0·15
		Mean	4·97	0·58	0·53	2·60	0·42	0·56	0·30	374	30·4	7·5	0·15
		Corr. coeff.	−0·50	−0·65	−0·99*	+0·18	−0·95*	+0·92	−0·68	−0·09	−0·92	−0·27	+0·08
Crested dogstail (*Cynosurus cristatus*)	1	0	..	..	..	..	..	..	..	..	..	..	..
	2	3	5·47	0·64	0·62	2·70	0·42	0·52	0·13	332	40·5	9·6	0·17
	3	6	5·35	0·45	0·56	2·31	0·46	0·55	0·11	178	33·9	6·8	0·23
	4	8	4·57	0·41	0·50	2·08	0·46	0·64	0·11	200	32·0	8·8	0·17
	5	12	4·38	0·35	0·44	1·69	0·40	0·53	0·10	163	24·9	6·8	0·15
		Mean	4·94	0·46	0·53	2·20	0·44	0·56	0·11	218	32·8	8·0	0·18
		Corr. coeff.	−0·92	−0·92	−0·99*	−0·99*	−0·31	+0·17	−0·88	−0·65	−0·99*	−0·70	−0·42

Meadow fescue (*Festuca elatior* sub-species *pratensis*)	1	0	6·91	0·92	0·76	3·16	0·51	0·84	0·29	560	43·3	5·6	0·20
	2	3	6·48	0·79	0·67	3·05	0·49	0·74	0·22	240	30·3	23·0	0·18
	3	6	4·96	0·55	0·55	2·36	0·44	0·58	0·24	210	22·3	6·9	0·17
	4	8	4·15	0·46	0·48	1·95	0·38	0·54	0·14	127	26·9	5·5	0·12
	5	12	3·77	0·42	0·44	1·81	0·36	0·61	0·10	114	23·1	6·6	0·14
		Mean	5·26	0·62	0·58	2·47	0·44	0·66	0·20	250	29·2	9·5	0·16
		Corr. coeff.	−0·96*	−0·95*	−0·97*	−0·95*	−0·98*	−0·81	−0·92*	−0·88*	−0·82	−0·36	−0·85
Tall fescue (*Festuca elatior* sub-species *arundinaceae*)	1	0	6·26	0·63	0·68	3·01	0·64	0·56	0·22	447	32·5	5·4	0·18
	2	3	..	..	..	..	..	..	..	..	..	..	..
	3	6	4·87	0·36	0·61	2·83	0·58	0·59	0·14	137	23·0	2·2	0·09
	4	8	4·12	0·34	0·49	2·04	0·50	0·40	0·12	206	17·1	3·4	0·09
	5	12	3·53	0·35	0·48	1·66	0·46	0·32	0·09	342	19·7	5·5	0·08
		Mean	4·69	0·42	0·56	2·39	0·54	0·47	0·14	283	23·1	4·1	0·11
		Corr. coeff.	−0·99*	−0·88	−0·94	−0·92	−0·97*	−0·80	−0·99*	−0·38	−0·88	−0·04	−0·91
Red fescue (*Festuca rubra* var. *genuina*)	1	0	..	..	..	..	..	..	..	..	..	..	..
	2	3	4·99	0·63	0·71	2·63	0·35	0·54	0·05	327	30·8	11·1	0·20
	3	6	4·55	0·56	0·59	2·32	0·28	0·42	0·09	241	30·1	14·5	0·19
	4	8	3·83	0·58	0·53	2·11	0·26	0·49	0·04	228	24·2	6·7	0·17
	5	12	3·42	0·48	0·44	1·69	0·19	0·38	0·03	302	19·6	8·7	0·21
		Mean	4·20	0·56	0·57	2·19	0·27	0·46	0·05	275	26·2	10·3	0·19
		Corr. coeff.	−0·97*	−0·95*	−0·99*	−0·99*	−0·99*	−0·82	−0·47	−0·50	−0·96*	−0·50	+0·35
Chewings fescue (*Festuca rubra* var. *fallax*)	1	0	..	..	..	..	..	..	..	..	..	..	..
	2	3	..	..	..	..	..	..	..	..	..	..	..
	3	6	3·80	0·33	0·51	1·67	0·38	0·53	0·30	170	13·9	3·9	0·13
	4	8	3·67	0·35	0·43	2·13	0·37	0·52	0·23	328	18·3	7·8	0·22
	5	12	3·60	0·30	0·38	2·05	0·29	0·42	0·12	361	20·6	7·2	0·13
		Mean	3·70	0·33	0·44	1·95	0·35	0·49	0·21	286	17·6	6·3	0·16
		Corr. coeff.	−0·99*	−0·78	−0·99*	+0·64	−0·97	−0·97	−0·99*	−0·85	+0·93	+0·60	−0·19
Mean of grass species			4·75	0·54	0·56	2·40	0·40	−0·50	0·17	264	28·9	8·2	0·15
Standard error of grass species			±0·16	±0·03	±0·02	±0·08	±0·02	±0·02	±0·01	±18	±1·8	±0·7	±0·01

* Denotes significance at 5% probability.

Cobalt.—The herbs, as a group, do not show a significantly higher mean cobalt-content than the legumes; nor have the legumes a higher one than the grasses. The only groups with a significant difference are the herbs and grasses, the first having more cobalt. There is very little variation within the herb group, the range being no more than 0·17 to 0·20 p.p.m. Of the legumes, lucerne is relatively disappointing although, under the conditions of the experiment, it contains an amount of cobalt which greatly exceeds the minimum for safety. The grasses range from 0·11 to 0·19 p.p.m., tall fescue being the poorest of these and red fescue the best.

Few of the species included in the investigation show any evidence of a relationship between cobalt and age; only 2 of the legumes and 2 grasses give significant negative correlations.

Discussion

The data presented in this paper make it evident that the inclusion of legumes in swards for either grazing or mowing could be justified on the grounds of mineral efficiency alone. It is even more plainly evident, however, that certain of the herbs are still better sources of minerals than the legumes, and that a good case can be made for their inclusion in mixtures. It is not suggested that the legumes can be replaced—even partially—as they are recognized as being the most important suppliers of protein. Two of the leguminous plants examined, lucerne and alsike, possess quite high mineral efficiency, particularly in respect of lime, lucerne being outstanding. Alsike is already an accepted component of many seeds-mixtures, but it is doubtful whether its employment on any larger scale could be justified on agronomic grounds. Lucerne is an immensely valuable species under certain clearly defined conditions of environment, but by reason of its slow establishment and dislike of competition it is never likely to be used on any considerable scale for inclusion in seeds-mixtures.

Of the herbs burnet, although exceptionally rich in magnesium, is not generally mineral-efficient, and agronomists do not appear to hold it in high esteem on other grounds. Nevertheless, it may be premature to conclude that this herb is never worthy of inclusion in seeds-mixtures. Stapledon [5] speaks very highly of it as a source of winter keep on limestone soils, and Oyenuga [6] has obtained some striking results from it in preliminary investigations on the availability of iron in grassland species.

Yarrow is undoubtedly of fairly high mineral efficiency, but is probably somewhat limited in its usefulness as a grassland species. Obviously of little value in a meadow sward, it is probably best adapted to sheep-grazing, where it would be less liable to take over the ground. It should not be forgotten, moreover, that yarrow establishes itself on soil types which normally tend to grow swards of rather poor mineral content. Yarrow may, therefore, be considered as a distinctly useful component of grazing swards under limited and defined conditions but as probably unsuitable for general employment.

The first record of the deliberate inclusion of plantain in seeds-mixtures may be that of Elliott [7]. Since then it has been in no more than occasional use, although it occurs naturally in very many swards, and there is a considerable body of opinion which holds it to be a valuable herbage species. Evans and Thompson [8] have said that it occurs widely in meadow swards in the Yorkshire dales and is highly regarded as a constituent of hay, more especially when fed to young stock. Stapledon [9] classes it as a herb having nutritive and medicinal properties. The value of plantain as a meadow plant has been depreciated on the grounds that it makes hay difficult to win, and this criticism is not easily disposed of. Its presence in any type of sward is considered by many to be undesirable in view of its habit of growth, and its apparent tendency to occupy more than its share of the ground. Milton [10], however, has shown that when grown either alone or in association with other grasses its capacity for producing dry matter is much greater than that of rye-grass. Moreover, Fagan and Watkins [4] have shown it to be particularly strong in calcium and chlorine and a good source of phosphorus and potassium. According to the former worker [11], the crude-protein content is high and the fibre low. The work of Moon [12] indicates that plantain is one of the best sources of the carotenoids, and Milton [13] has provided evidence of its high palatability. The results of the present investigation show it to contain more calcium than any other species examined, with the single exception of lucerne. It contains more sodium and iron than any other species—legume, herb, or grass. It has as much magnesium as chicory and is second only to this herb in chlorine-content. Of no element determined can it be considered to contain unsatisfactory amounts.

That chicory is not without value as a fodder plant has been known for many years, and it was very highly regarded by Elliott, who included it in a large number of his mixtures. Since that day it has been used in seeds-mixtures to a limited extent. This plant is known to have certain valuable qualities. It produces a large bulk of dry matter and is deep-rooting. The latter characteristic has important cultural effects and enables chicory to provide feed during droughty periods when pastures are normally burnt up. It appears to have been understood for a long time that chicory is exceptionally mineral efficient, although the authors are uncertain whether this belief was founded on analytical evidence or whether it arose from observation alone. High mineral efficiency is another quality which obviously arises from its deep-rooting habit. Chicory has certain disadvantages which are equally well known, and which limit its use as a component of meadow or pasture. It is slow to establish, and easily eaten out during the early stages if overgrazed, a result of its extreme palatability to all classes of stock. Incidentally, it is very liable to severe damage by hares, which may eat right down into the root-stock; the partiality of these animals for chicory was noted by Elliott [7] and may be observed by anyone who grows it in an area where they are plentiful. Once established it may persist, even under regular grazing, for a considerable number of years. In meadow swards it adds to the difficulty of winning hay, and later tends to make the

latter very dusty. The analytical data presented in this paper show chicory to be quite outstanding as a source of the mineral elements. Its content of silica-free ash is extremely high, and of 10 elements determined there are 5 of which chicory contains more than any other species examined here. Its content of the remaining 5 elements is high in every case; it contains as much cobalt as plantain, is second to this plant in respect of calcium, sodium, and iron, and is exceeded in magnesium only by burnet. It is a safe conclusion that there is no other sown grassland species of equal mineral efficiency. The desirability, from a nutritional standpoint, of allowing grazing stock access to it would seem to be obvious, and it remains for the agronomist to devise means of doing so.

Although the grasses show less variation, as between species, in respect of any particular ash constituent, in silica-free ash they compare very unfavourably, generally containing 50 per cent. or less of that in both herbs and legumes. The superiority of the herbs and legumes is most marked in the elements calcium, magnesium, phosphorus, and manganese; only in chlorine and copper are the differences of little account. In so far as it is possible to assess all-round mineral efficiency the more reputable grasses, e.g. timothy, cocksfoot, and rye-grass, are good, but the fescues are relatively inferior, the notable exception being that meadow fescue would appear to be the most mineral-efficient of all the grasses examined.

The authors fully realize that the foregoing results may not always be reproduceable on soils and under climatic conditions dissimilar to those in east Northumberland. It seems, however, reasonable to believe that, with the possible exception of a few species of restricted habitat, the general order will be maintained. This belief is supported by the large measure of agreement already found to exist between the results obtained by the authors in north-east England and the results of workers in other parts of the United Kingdom, and indeed overseas.

The correlation-coefficients show that, in general, the mineral contents decline significantly with advancing age, a decline more clearly marked in the major elements than in the trace elements. Sodium, in the legumes, provides an outstanding exception, there being three positive correlations from four species. In some cases maximum or minimum content was reached in mid-season. It might appear at first sight that the grasses show a more marked seasonal correlation than the other two groups, but a statistical examination does not indicate any significant difference between the three. There are, however, some well-marked and significant species differences. Lucerne and sainfoin contain very satisfactory amounts of the minerals in the early stages of growth, but tend to fall off more rapidly than other members of their group, e.g. trefoil. Of the herbs, chicory is less affected by advancing maturity than the others. These differences may have some practical implications, and might conceivably be considered in the design of seeds-mixtures for specific purposes. Satisfactory mineral efficiency in the later stages of growth would seem to be of greater importance in a sward designed for mowing than in a grazing ley. In the latter, fairly rapid decline with maturity should, under proper management, be of little moment.

It is possible to visualize circumstances under which the establishment of swards, designed solely for producing feed of high mineral efficiency, would be worth while, as for example on a unit of large area where the bulk of the grassland was of relatively poor quality. Such special swards might be used for drying, ensiling, or rotational grazing, as convenient. It would not necessarily follow that herbage grown primarily as a source of minerals would be poor in protein and other of the important dry-matter constituents; it is indeed probable that it would be little inferior in these respects to the normal ley.

The artificial drying of mixtures, whether designed solely as sources of minerals or containing sufficient of certain selected species to ensure a reasonably high mineral efficiency, would probably present the same sort of difficulties as are known to be encountered in hay-making. Where appreciable quantities of such herbs as chicory or plantain are present, the grasses are likely to be overdried. Some consideration might well be given to the possibility of drying pure stands; chicory, for example, should produce a meal of exceptional all-round mineral content, but which at the same time would be something more than a mere mineral mixture. The ensilage of herb-containing swards would appear to present no difficulties whatsoever, and this would seem to be the most likely means of conserving them.

Although it may now be regarded as certain that the inclusion in seed-mixtures of species not now in common use is capable of increasing the mineral efficiency of swards, it is less certain that any such increase is necessary on the average farm. There is little evidence acceptable to the scientific worker to suggest that any substantial improvement in live-weight production, yield of milk, or growth of young stock can be obtained, under average conditions, by increasing the amount of mineral matter available to stock. Nevertheless, thousands of competent farmers are annually spending considerable sums of money on mineral supplements, and it would be rash to assume that this expenditure is being incurred without any thought of possible return. If minerals are to be fed, then it may be worth while considering whether it would not be more economic to feed them in the form of highly mineral-efficient herbage. There are, moreover, other reasons why the latter source of supply might be preferable; to instance only one, the possible risk of excessive consumption, though admittedly inconsiderable, must be taken into account. In point of fact, the inclusion of a certain proportion of highly mineral-efficient species in a mixture involves little if any additional cost, and there is not much evidence that it has any appreciable adverse effect on the yielding capacity of the sward, or on its quality in respect to components other than the minerals. The productivity and growth-rate of the grazing animal constitute the only good criteria of the quality of a feed, and it is certain that critical field experimentation will be necessary before valid conclusions on this matter can be reached.

Summary.—The ash constituents, including some trace elements, have been determined in 16 herbage species comprising 4 legumes, 4 herbs, and 8 grasses at different stages of growth.

The herbs and legumes have been found much more mineral-efficient than the grasses, being superior to the latter in all elements. Both herbs and legumes are good sources of minerals, herbs proving the better except in calcium, phosphorus, and magnesium.

Chicory, and to a slightly lesser extent plantain, were outstandingly mineral-efficient when compared with all of the other better-known grassland plants. Among the legumes, lucerne and alsike were superior to trefoil and sainfoin, being particularly strong in calcium. The more reputable grasses, e.g. rye-grass, cocksfoot, and timothy, were in general superior to nearly all of the others, but meadow fescue provided a notable exception, being richer in the mineral elements than any other grass.

In general, the silica-free ash and its components declined as maturity approached. Sodium in the legumes proved exceptional, significant positive correlation between this element and age being shown to exist in three out of four species.

Some practical implications of the above findings have been discussed, and suggestions made for the better utilization of species shown to be exceptionally rich in the more important ash constituents.

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THE COST OF FOOT-AND-MOUTH DISEASE

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On a few occasions in the past speculations have been made on the financial loss suffered by the agricultural industry from foot-and-mouth disease. These, however, have been little more than bare statements without supporting evidence or concerned with one aspect only, such as the average reduction in value of animals which have suffered an attack, or the value of animals which have died as a result of the disease. The present inquiry is a more comprehensive attempt to reach conclusions. Indo-Pakistan could no doubt have been taken as an example, but it seemed far preferable to restrict the inquiry to Pakistan, largely because the necessary data were readily available, also because the areas and cattle populations involved in Pakistan, though large, are a good deal smaller than those of the subcontinent as a whole, and consequently there are less variables to contend with. Even so, the problem is sufficiently complicated because western and eastern Pakistan, though politically single, are agriculturally quite distinct. For this reason separate estimates have to be made for these two parts of the country. Finally, it must be made clear that there is no implication that Pakistan is more heavily infected than any other country similarly situated.

In this investigation there is, of course, no pretence to accuracy, and difference of opinion is to be expected on the reasoning upon which some of the calculations are based. In anticipation of criticism it may be said now that every effort has been made to keep the estimates conservative, that the attempt concerns only the measurable losses, and that the estimates are thought to provide some reasonably solid basis for crystallizing one's ideas.

Cattle population.—The population of cattle, including buffaloes, in Pakistan may be set down as follows:

	Oxen	*Buffaloes*
W. Pakistan	9,555,500	4,854,900
E. Pakistan	16,039,007	583,665
	25,594,507	5,438,565

The figures are taken from the following censuses: NW. Frontier Province and Sind 1945, W. Punjab and E. Bengal 1940, Khairpur 1939, Bahawalpur and Sylhet 1935, Baluchistan (estimate only).

Goats, though susceptible to foot-and-mouth disease, are not considered.

Attack-rate.—Here it is especially important that estimates should be conservative, since the attack-rate forms the basis of most of the calculations that follow. Unfortunately there is no proper knowledge of the extent of the disease in the country and at the outset assumptions are necessary. In the first place, the effect of the nutritional state of the animal on its reaction to infection is now a well-established fact; for this reason and owing to the greater weight of the cattle, lesions may be expected to be more severe in the more robust oxen of W. Pakistan than

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in the smaller and less well-nourished animals of E. Pakistan. Thus, in the Fourth Progress Report of the Foot-and-Mouth Disease Research Committee of Great Britain [1], it is recorded that cattle with well-developed mouth lesions are much more infective for other cattle than animals with poor mouth lesions or animals undergoing otherwise abortive reactions. This is one reason why in Bengal (E. Pakistan) the disease may be expected to be less widespread. Another reason, pointed out by Mr. S. M. Ali, is that in Bengal many of the cattle live in very small units, so reducing the chances of their being infected; also more foot-and-mouth disease may be expected on the borders of the country than in the interior.

For the purpose of the inquiry, it is taken that in W. Pakistan foot-and-mouth disease is so prevalent that one-half of the oxen are attacked once in their lifetime. This is quite a conservative statement, when it is remembered that many get it twice or even thrice. With buffaloes, the incidence is taken as half that in oxen, apart from, or owing to, the disease being milder. In E. Pakistan we take it that, instead of one-half of the oxen as in the west, one-eighth will be affected once during their lifetime and that the incidence in buffaloes is again half that in oxen.

If we assume that 30 per cent. of the ox population are breeding cows with a fertility-rate[1] of 66 per cent. and that the population is remaining fairly steady, the average duration of life would work out at about 8 years. It is sufficient to make the same assumption with buffaloes, for although breeding she-buffaloes in Indo-Pakistan form 46 per cent. of the buffalo population the mortality in the young is higher. This would mean that 12·5 per cent., say 12 per cent., of the ox population would suffer every year if every animal were attacked once in its lifetime and 6 per cent. would so suffer if, as in W. Pakistan, every other one were attacked once. With buffaloes the figures would be 3 per cent. instead of 6 per cent. In E. Pakistan the corresponding figures would be 1·5 and 0·75 per cent. More commonly animals of the lower age-groups will be attacked.

In estimating the overall attack-rate, the question was considered whether in the first place a deduction ought to be made in respect of the lowest age-group, viz., birth to 6 months, since that is a period when mortality is heavy, and when death would remove from the population many animals which might otherwise have caught foot-and-mouth disease. It was decided, however, to make no such allowance because most of the deaths during early life occur within the first two months, so that the census figures for the youngest stock will be made up in part of animals which have escaped this early mortality.

Thus taking as the annual attack-rate in W. Pakistan 6 per cent. with oxen and 3 per cent. with buffaloes, in E. Pakistan 1·5 per cent. with oxen and 0·75 per cent. with buffaloes, the number of animals affected every year becomes:

	Oxen	*Buffaloes*
W. Pakistan	573,330	145,647
E. Pakistan	240,585	4,377
	813,915	150,024

[1] This term is used to include both conception-rate and calf mortality.

These figures, however, have to be further subdivided because the composition of the population in respect of young stock, adult females, and adult males differs as between oxen and buffaloes and also in different parts, also because we must assume that the disease has its greatest incidence among young stock, say from 3 months to 3 years old. In conformity with this, if we say that of the oxen affected each year 50 per cent. are young stock, 25 per cent. adult females, and 25 per cent. adult males, then we can assume that with buffaloes in W. Pakistan the respective proportions are roughly 55, 35, and 10, and in E. Pakistan 20, 25, and 55. These proportions are arrived at by considering the distribution of the various categories of stock, as given for different regions in the Report on the Marketing of Cattle in India [2]. For this purpose the distribution shown for Bengal is taken as representing E. Pakistan, and the overall distribution for the Frontier Province, Punjab, and Sind as representing W. Pakistan.

The total attack-rate figures are therefore to be redistributed as follows:

	Oxen	*Buffaloes*
W. Pakistan:		
young stock	286,666	80,106
adult females	143,332	50,976
adult males	143,332	14,565
	573,330	145,647
E. Pakistan:		
young stock	120,293	876
adult females	60,146	1,094
adult males	60,146	2,407
	240,585	4,377

The categories of loss due to foot-and-mouth disease, for the purpose of this paper, may be set out as follows:

A. Mortality due to the disease. B. Loss in bodily condition. C. Loss of milk. D. Loss of working capacity.

These are sources of loss which together affect practically all classes of the cattle population and which one can attempt to measure, but there are other important factors for which no estimates can be made. These may be given as follows.

(*a*) There is evidence of a definite seasonal incidence of foot-and-mouth disease in India. Edwards [3] noted that most of the outbreaks reported during a single year in the Central Provinces occurred during the winter season when the cattle are better nourished. Figures for 66,312 outbreaks occurring during periods of 6 to 8 years between 1936 and 1943 in thirteen provinces are available to me. The distribution and highest monthly incidence of these were as given on p. 26.

Briefly, the maximum incidence in W. Pakistan is roughly from April to June, in U.P. and Bihar it is roughly the same with secondary peaks in September (very pronounced in U.P.), in Assam during the summer, and in the remaining provinces during the cool season. In W. Pakistan and N. India the greater incidence in the spring is presumably due to

greater movement of cattle during these months, as well as to the more numerous fairs held at that time. At this spring season also the cattle are engaged in threshing and carting operations, as well as in cultivation of the land for the *kharif* (summer) crops.

Province	*Outbreaks*	*Max. incidence*	*Years*
Punjab	9,217	May–June	7
NW. Frontier Province	1,061	April to July	6
Sind	778	March to May, January	6
Baluchistan	274	April–May	7
United Provinces	15,177	April–May, August–September	8
Bihar	6,443	March to May, September	8
Assam	4,133	June to September	6
Bengal	6,302	November	7
Bombay	9,091	January to March	7
Madras	6,481	,, ,,	7
Orissa	5,837	,, ,,	8
Central Provinces	1,385	,, ,,	7
Ajmer-Merwara	133	,, ,,	7

(*b*) It is pointed out in the Cattle Report [2] that owing to a number of causes there are seasonal variations in price which relatively increase or diminish the losses. Thus in W. Pakistan bullocks are in greater demand and fetch higher prices in the autumn and spring when they are required for agricultural operations. Outbreaks at such times will cause far heavier financial loss than at more quiescent periods, and the cost of replacements will be higher. And, as pointed out under (*a*), outbreaks are more frequent in the spring months in W. Pakistan. Also, in the spring, dairy cows cost more because that is the main calving season. Cows which lose their calves early in lactation will show a relatively higher reduction in milk yield, quite apart from the fact that cows with calf at foot are worth more in the market.

(*c*) It is recognized that the disease causes extensive dislocation to routine animal management and breeding. For instance, on the military farms severe foot lesions in heavy and valuable bulls can prevent service for weeks and completely upset the breeding and milk-production programmes. Outbreaks of the disease may interfere with plans for vaccination against rinderpest. The fact that in certain years and in certain areas famines or floods or other diseases like rinderpest may remove cattle, which might otherwise fall victims to foot-and-mouth disease, is cold comfort. A final point for which no allowance can be made is the human service and the medicines required for treating sick animals.

(*d*) Quite apart from the very important fact that outbreaks leave behind them the seeds of further outbreaks, foot-and-mouth disease is well known to have troublesome *sequelae*. Myiasis of the feet is a common and serious complication in a warm country, also pedal deformities leading to chronic lameness. Other recognized results are abortion, and the awakening of latent cases of mastitis. What may be called 'panting disease' [4] is another sequel to be mentioned, though it is of little concern for the present purpose, because it mainly affects cattle with

European blood and these form an insignificant proportion of the cattle population. When foot-and-mouth disease occurs in animals already suffering from other infections, such as piroplasmosis, or if the outbreak occurs at times of heavy rains or floods, effects are likely to be more severe and mortality is said to be increased.

It would be quite impossible to make allowances for sources of loss such as those mentioned, so any calculations that can be made necessarily oversimplify the problem.

A. *Mortality due to the Disease*

Many of the Indian provincial reports give figures relating to numbers of cattle dying from the disease and its complications. A few of the reports give at the same time the number of cattle said to be affected. These, for what they are worth, together with some statistics from the military farms, may be summarized as follows:

Province or organization	*Period*	*Numbers attacked*	*Number of deaths*	*Mean mortality-rate (per cent.)*	*Remarks*
Punjab . .	1904–12	600,008	8,344	1·39	oxen
Sind . .	1936–42	28,940	675	2·33	,,
Bombay . .	1937–41	165,286	701	0·42	,,
Bihar . .	1935–41	150,192	544	0·36	mainly oxen, a few buffaloes
Army Veterinary Service Report	1934–7	3,859	43	1·11	oxen
Military farms .	1945–6	2,475	24	0·97	,,
,, .	,,	4,940	84	1·7	buffaloes
Sind . .	1937–42	5,861	55	0·94	,,
Bombay . .	1937–41	33,069	165	0·5	,,

Thus there is great variability, even in the mean percentage figures for mortality-rates, perhaps due in part to varying proportions of young animals. For present purposes it is proposed to take 1·0 per cent. as the mortality-rate for oxen. This is justified by the fact that this rate is close to the most frequent mean figure in populations totalling over 950,000 attacked, and is intermediate between that noted for the better-class animals of the Punjab and the poorer types of Bihar. Since foot-and-mouth disease in India is usually mild, and in order to be still more conservative, we may restrict the rate to young stock attacked. Since in buffaloes the disease is still milder, the death-rate should be distinctly lower than that decided for oxen. It would therefore be wiser to ignore the figures given and assume a rate, say, one-quarter that of oxen, or 0·25 per cent. An average valuation of Rs 200 will not be excessive.

The loss therefore is 4,069 young oxen at Rs 200 . .		813,800
,, ,, 203 ,, buffaloes at Rs 200 .		40,600
	Rs	854,400

B. *Loss in Bodily Condition*

This may be put under two subcategories:

(*a*) Animals which are slaughtered shortly after the attack, because owing to extreme loss of condition it is no longer considered economical to maintain them.

(*b*) Animals which lose condition as a result of the attack and to which the owner decides to give extra food for, say, three months.

Subcategory (*b*) concerns W. Pakistan only, where fodder is rather more plentiful. The great majority of animals which survive an attack will fall under neither of these heads. They are either left to recover without any extra attention or some of them may be sold at subnormal prices during the period of temporary incapacity. Let us assume that for every animal that dies naturally of the disease one more will fall under subcategory (*a*), and that 10 per cent. of the remaining young stock will fall under subcategory (*b*). Since in both cases the losses will fall most heavily on the younger age-group (3 months to 3 years), for purposes of calculation we may assume that losses are restricted to this group and take as an average live-weight 200 lb. The calculations are as follows:

With (*a*), a loss of 50 lb. in body-weight is assumed. Of the 150 lb. live-weight at time of slaughter, 55 per cent. or 82·5 lb. is flesh, for which in 1943 the butcher might have been expected to pay 4 annas per lb., or say, Rs 20 [2]. The total payment to the owner may be put at Rs 30 to include skin and offal, and is to be deducted from the cost of the replacement.

The loss therefore is 4,069 young oxen at Rs 170 . .	691,730
,, ,, 203 ,, buffaloes at Rs 170 .	34,510
Rs	726,240

With (*b*), 50 lb. live-weight per head are to be recovered in the case of 10 per cent. of young cattle in W. Pakistan which have survived natural death or necessary slaughter following the attack. The cost of the extra food per lb. live-weight gain is put at 6 annas.

	Oxen	*Buffaloes*
Attack-rate	286,666	80,106
Death and slaughter	5,732	400
Survivors	280,934	79,706
10 per cent.	28,093	7,970
Live-weight to be gained (at 50 lb. each)	1,404,650	398,500

Total lb. 1,803,150 at 6 annas = Rs 676,181.

Total of (*a*) and (*b*) Rs 1,402,421

C. *Loss of Milk*

It is practically impossible to make a close estimation of this source of loss, owing among other things to the varying uses to which milk is

put, the differing prices of liquid milk and milk products, as well as of town and country milk, and seasonal effects on prices. According to the Report on the Marketing of Milk in India and Burma [5], the total Indian milk production on a percentage basis is distributed as follows:

Province or State	*Cow*	*Buffalo*
NW. Frontier Province (with agencies and tribal areas)	1·56	1·44
Punjab	13·53	25·45
Bahawalpur State (estimate)	1·03	1·05
Sind	3·90	3·30
Khairpur State	0·36	0·21
Baluchistan and States	0·65	0·02
Bengal	13·17	0·73
	34·20	32·20

Making the necessary allowances for the partition of the Punjab and Bengal the percentages may be in the neighbourhood of 23·92 and 21·75 for cow and buffalo milk respectively.[1] These figures are of interest in showing the high production of the areas now included in Pakistan in relation to their much smaller extent in the Indo-Pakistan subcontinent. The area of Pakistan is about 15 per cent. of that of the whole subcontinent.

In estimating the loss of milk, cows and buffaloes have to be considered separately for reasons of which some have already been mentioned. In the two species the disease has different characters, the milk yield is different, the relative proportions of the cows in ox and buffalo populations differ, and for buffaloes the proportions are also different as between E. and W. Pakistan, finally in E. Pakistan a larger proportion of females is used for work. The category of adult females will thus include milch animals as well as females which are used for work, the latter forming 10 per cent. of the adult females in W. Pakistan and 30 per cent. in E. Pakistan. Hence deductions for working females have to be made from the number of animals affected, but as it is assumed that the death-rate in adults is negligible no deductions are made on this account. Of milch cows 60 per cent. are taken as wet, and of milch buffaloes 50 per cent. The average milk production per lactation, on the basis of estimations of yields given by Wright [6] and in the Cattle Report [2], is taken as follows: W. Pakistan cows 1,300 lb., W. Pakistan buffaloes 2,000 lb., E. Pakistan cows 420 lb., and E. Pakistan buffaloes 960 lb. Deductions of 10 per cent. in yield due to foot-and-mouth disease are assumed in all cases, such a reduction in yield being equivalent to a cow being dry for one month of her lactation period. This estimate of loss is perhaps too far on the conservative side for the higher-yielding cows of W. Pakistan, especially as they may be expected to be in fairly good condition, and to be attacked in March–April when many of them are at the flush period. With buffaloes, however, which are at the flush period in September–November, and the lower-yielding cows

[1] Roughly 60 per cent. of the Punjab falls in W. Pakistan. The portions of Bengal and Sylhet lying in E. Pakistan amount to about 63 per cent. of undivided Bengal.

of E. Pakistan, the average reduction in yield may probably be safely put at 10 per cent.

We may now proceed to estimate the loss of milk, as follows:

	W. Pakistan		*E. Pakistan*
		Oxen	
Adult females attacked	143,332		60,146
Working	14,333		18,043
Milch	128,999		42,103
Wet	77,399		25,261
Yield (at 1,300 lb.)	100,618,700	(at 420 lb.)	10,609,620
For calves (reduction of 1/5)	80,494,960		8,487,696
10 per cent.	8,049,496		848,769
[1]Sold liquid	2,495,344		263,118
Sold as milk products	5,554,152		585,651
[2]Prices	Rs 520,326		Rs 54,866
		Buffaloes	
Adult females attacked	50,976		1,094
Working	5,097		328
Milch	45,879		766
Wet	22,939		383
Yield (at 2,000 lb.)	45,878,000	(at 960 lb.)	367,680
For calves (reduction of 1/10)	41,290,200		330,912
10 per cent.	4,129,020		33,091
[1]Sold liquid	1,279,996		10,258
Sold as milk products	2,849,024		22,833
[2]Prices	Rs 266,904		Rs 2,135
	Total Rs 844,231		

[1] According to Wright [6], utilization of milk produced in India and Burma is about 31 per cent. as liquid milk and 69 per cent. as products, mainly *ghee*.

[2] General price figures are mentioned by Wright as Rs 5 per maund (80 lb.) for liquid milk and Rs 2/12 for *ghee* produced from one maund of milk. These prices were considered to be ruling prior to 1937. For the present purpose a 50 per cent. increase has been allowed, but even this undoubtedly underestimates more recent advances in price.

No account is taken of the diminished supplies of *lassi*, since this product of *ghee*-manufacture is ordinarily kept for home use. Nor is account taken of the loss of milk due to the fact that the calf, whose dam has suddenly gone dry or practically so, has to be fed on the milk of other cows.

D. *Loss of Working Capacity*

Three factors have to be considered under this heading:

(*a*) Cost of feeding the affected animal during the time it is actually immobilized.
(*b*) Cost of feeding the affected animal to bring it back into condition.
(*c*) Loss on cultivations.

Under (*a*), similar calculations are required to those just set out in Section C. From the percentage attack-rate of adult males, we deduct 2 per cent. to allow for breeding bulls and the few adult males that are not used for work. To this we add the small proportion of working cows and she-buffaloes. We assume that the overall working period in each

year is 8 months and that it is only during this period that the loss under this head has to be considered. We assume further that the average period of immobilization, including 6 days in which the lesions are in the eruptive stage when the animal eats little, is 28 days, and that the daily cost for 22 days of feeding the idle animal is 6 annas in W. Pakistan and 3 annas in E. Pakistan, where the available feed is minimal.

The calculations are as follows, variations in seasonal incidence being neglected:

	W. Pakistan		*E. Pakistan*
	Oxen		
Adult males attacked	143,332		60,146
Deduct 2 per cent. non-working males	2,867		1,203
Add working females	14,333		18,044
Total working animals attacked	154,798		76,987
Working for 8 months	103,198		51,325
Feed (at Rs 8/4)	Rs 851,383	(at Rs 4/2)	Rs 211,716
	Buffaloes		
Adult males attacked	14,565		2,407
Deduct 2 per cent. non-working males	291		48
Add working females	5,097		328
Total working animals attacked	19,371		2,687
Working for 8 months	12,914		1,791
Feed (at Rs 8/4)	Rs 106,540	(at Rs 4/2)	Rs 7,388
		Total Rs 1,177,027	

Under (*b*), it was finally decided to make no allowance. The animal husbandry conditions in the country are such that in the dry season most animals normally become thin, that is they lose fat or food reserve, but they are still capable of working and in practice they continue to do so. The reserve lost is replaced during the rains by natural grazing, which can be said to cost nothing.

Under (*c*), loss on cultivations caused by foot-and-mouth disease, there are two basic facts to be considered: the proportion of the market value of the produce received by the grower, and the bullock-power used for cultivation.

As to the first, the grower's share, taken in this instance as 50 per cent., is considered, since in this inquiry questions of loss are examined mainly from the agricultural standpoint.

As to the second point, the following statement may first be made. We have estimated that of the oxen annually attacked one-quarter are adult males and the rest adult females and young stock. Since the annual overall attack-rate for oxen is 6 per cent., this means that the annual rate for adult males is $1\frac{1}{2}$ per cent. Since, however, they work not for 12 months in the year but for 8 months only, the attack-rate over the 12 months becomes 1 per cent. One per cent. would be the fall in crop-yield if every affected adult male suffered throughout the 8 months, but since the loss of power by affected animals may be said to endure for 3 months only during and after the attack, the crop-yield is lowered not by 1 per cent. but by 3/8 of 1 per cent. If again we assume that in nine-tenths of the instances some arrangement is made by the owner for supplementing the animal draught-power as by utilizing bullocks or

other draught animals borrowed from neighbours, the crop yield may be said to be lowered by 3/80 of 1 per cent.

The matter, however, is not quite as straightforward as this, for reasons explained above. Thus (1) not quite all the adult males are working animals and some adult females have also to be included; (2) the attack-rate in buffaloes is taken as half that in oxen, and for all cattle the attack-rate in E. Pakistan is taken as one-quarter that in W. Pakistan; (3) the distribution among animals attacked in respect of young stock, adult females, and adult males is different as between oxen and buffaloes, and as between buffaloes in W. and in E. Pakistan.

It is necessary therefore to work out, from (*a*) above, the ratios between the attack-rate in adult males, expressed as a percentage of the total attack-rate, and the similar figure for working animals. These ratios are as follows:

W. Pakistan oxen. Adult males 25 per cent., working animals 27 per cent.
W. Pakistan buffaloes. Adult males 10 per cent., working animals 13·3 per cent.
E. Pakistan oxen. Adult males 25 per cent., working animals 32 per cent.
E. Pakistan buffaloes. Adult males 55 per cent., working animals 61·3 per cent.

Then, with

W. Pakistan oxen,

27 per cent. of the 6 per cent. annual attack-rate is 1·6 per cent. and for 8 months 1·07 per cent.

W. Pakistan buffaloes,

13·3 per cent. of the 3 per cent. annual attack-rate is 0·4 per cent. and for 8 months 0·27 per cent.

E. Pakistan oxen,

32 per cent. of the 1·5 per cent. annual attack-rate is 0·48 per cent. and for 8 months 0·32 per cent.

E. Pakistan buffaloes,

61·3 per cent. of the 0·75 per cent. annual attack-rate is 0·46 per cent. and for 8 months 0·31 per cent.

For W. Pakistan we may take the reduction in crop yield as 3/80 of 1 per cent., since only about 10 per cent. of the working animals are buffaloes; for E. Pakistan we take 3/80 of 0·3 per cent. The final calculation is shown in Table I, which gives the production and market value of the major crops in Pakistan. The total value of these crops to the grower is Rs 4,732,673,000, so the total loss under this heading comes to Rs 923,839.

Summary of Annual Loss

A.	Mortality	854,400
B.	Loss in bodily condition	
	(*a*) slaughter	726,240
	(*b*) extra feeding	676,181
C.	Loss of milk	844,231
D.	Loss of working capacity	
	(*a*) feed during idleness	1,177,027
	(*b*) extra feeding of work animals	0
	(*c*) reduction in crop yield	923,839
		Rs 5,201,918

TABLE I. *Production and Market Value of the Chief Crops grown in Pakistan**

Crop	W. Pakistan			E. Pakistan		
	Production (md.)	*Approx. rate per md. (Rs)*	*Approx. value (Rs)*	*Production (md.)*	*Approx. rate per md. (Rs)*	*Approx. value (Rs)*
Rice	28,616,000	23	658,168,000	211,811,000	23	4,871,655,000
Wheat	104,356,000	13	1,356,628,000	598,000	29	17,371,000
Maize	13,328,000	8	106,624,000	..	..	..
Barley	3,094,000	10	30,940,000	1,548,000	14	21,679,000
Jowar	7,056,000	7/8	52,920,000	..	..	..
Bajra	12,236,000	7/8	91,770,000	..	..	..
Gram	11,424,000	10	114,240,000	..	..	..
Rape and mustard	3,404,800	20	68,096,000	2,031,000	30	60,932,000
Sesamum	..	..	..	919,000	24	22,057,000
Linseed	..	..	..	325,000	16	5,215,000
Cotton seed	10,724,000	10	107,240,000	..	..	..
Potato	1,456,000	10	14,560,000	8,905,000	23	204,827,000
Sugar-cane (*gur*)	15,568,000	13	202,384,000	9,137,000	32	292,389,000
Cotton	6,050,000	23	139,150,000	..	..	..
Jute	..	..	..	34,210,000	25/8	872,432,000
Tobacco	789,600	50	39,480,000	1,538,000	74/8	114,590,000
			2,982,200,000			6,483,147,000
Approx. value to producer at 50 per cent.			1,491,100,000			3,241,573,500
3/80 of 1 per cent.			559,162	3/80 of 0·3 per cent.		364,677
			Total Rs 923,839			

* Figures for W. Pakistan are mostly for 1944–5. For cotton seed and cane, figures are for 1948; for potato the estimate is for W. Punjab. Approximate market values provided by the Co-operation and Marketing Department, Government of Pakistan.

Figures for E. Pakistan taken from a publication by Dr. S. A. Husain, formerly Director of Agricultural Marketing, E. Bengal.

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Say, Rs 5,200,000 or £390,000 a year at the pre-devaluation rate of sterling.

Summary

In attempting to assess the measurable loss to a country due to foot-and-mouth disease, Pakistan has been taken as an example. The annual loss through various factors connected with the disease is estimated to be at least Rs 5,200,000 (£390,000), or roughly Rs 17,000 per 100,000 of a cattle population, 17 per cent. of which are buffaloes. It must be emphasized that the estimations necessarily omit losses from various causes that cannot be measured.

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THE ECONOMICS OF FERTILIZING NATURAL VELD, AS SHOWN BY DAIRY ANIMALS, FRANKENWALD, 1951

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FERTILIZER experiments on natural veld were started in 1933 at 'Frankenwald', the Botanical Research Station of the University of the Witwatersrand, by the Agricultural Advisory Section of African Explosives and Chemical Industries, Ltd. Frankenwald lies between Johannesburg and Pretoria at an altitude of approximately 5,500 ft. The soils are of granitic origin, coarse, sandy, and deficient in major plant-foods, with a pH ranging from 4·5 to 6·0, and are thus considered agriculturally poor. The average seasonal rainfall over 14 seasons is 31·11 in., most of which falls in the summer growing-season from November to March. In the 1949–50 season it was decided to discontinue the use of beef steers, which had been used from 1933 to 1949 [1, 2], and to use dairy cows as the grazing animals in a modified experiment.

The botanical composition of the herbage on control and treated areas in 1949 is given by Hall *et al.* [3] as follows:

Grasses	*Treatment*	
	Control %	*N_3PK* %
Tristachya hispida	4·2	1·4
Trachypogon plumosus	4·4	0·6
Elyonurus argenteus	4·0	..
Eragrostis chalcantha and *E. capensis*	8·1	..
Digitaria tricholaenoides	1·1	1·9
Heteropogon contortus	1·4	..
Harpechloa falx	0·9	2·9
Eragrostis spp.	..	17·7
Cynodon dactylon	..	5·5
Cymbopogon excavatus	0·8	0·9
Aristida spp.	0·9	..
Other grasses	4·7	5·2
Non-grasses	0·8	0·9
Total basal cover	31·3	37·0

Details of Experimental Treatments

Two treatments were compared in this experiment, a control that received no fertilizer, and an N_3P treatment where N_3 symbolizes nitrogen in the form of sulphate of ammonia (S/A) at the rate of 600 lb. per morgen[1] in three dressings of 200 lb. each, and P represents one annual dressing of a 400-lb. mixture of rock phosphate and superphosphate. The fertilizers were broadcast over the veld by machine, and the nitrogenous fertilizers were applied after rains of ½ in. or more. In the previous experiments Meredith [2] showed that the stocking-rate

[1] One morgen = 2·116 acres.

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for these pastures receiving an N_3PK dressing was approximately one beast to 0·7 morgen, and that of the control veld, one beast to 1·3 morgen. Using these data, the cows were divided into two groups of six animals each; one group grazing on 4 morgen of fertilized veld and the other group on 8 morgen of unfertilized (control) veld. The entire experimental area was divided into 1-morgen plots to facilitate rotational grazing. Friesland cows were purchased in 1949 which were as alike as possible with regard to age, weight, conformation, stages of lactation and gestation, and milk production. In order not to mask the effects of the treatments it was decided to use comparatively low-producing animals, i.e. animals producing 3–4 gallons of milk per day. In addition to the plots used for grazing, a further series was set aside for mowing and hay production only. In this series 4 morgen were treated with N_3P dressing and 8 morgen used as a control. The hay mown from these treatments was weighed and sampled after each mowing when it had air-dried. The samples collected were analysed for nitrogen, phosphorus, potassium, moisture, soluble ash, and total ash.

Methods used in Determining Yields

All animals were milked twice a day, morning and evening, and the production in lb. of milk was recorded for every cow. Group production was calculated for every month on the basis of lb. of milk produced per morgen. These records for the grazing season were then statistically analysed using 'Student's' method. Butter-fat tests were made every 28 days, whenever possible, with the 'Gerber' testing apparatus, and recorded as a percentage for each cow. A record of the amounts of concentrates fed to each animal per day was kept throughout the experimental period.

The yield of total digestible nutrients (T.D.N.) was calculated as follows: T.D.N. $=$ (3·53 $\times$ live-weight gained per morgen) $+$ live-weight maintained per morgen $\times \frac{7{\cdot}76}{1{,}000} +$ (T.D.N. per morgen in milk produced) $+$(T.D.N. per morgen in surplus hay from grazing plots) $-$ (T.D.N. in any concentrates fed).

The above formulae were given in the Preliminary Report of the Joint Committee on Pasture Investigation Technique [4] and outlined by Nevens [5]. The term 'live-weight maintained per morgen' is derived from the $\frac{\text{average weight} \times \text{grazing days}}{\text{no. of morgen}}$. The T.D.N. in the milk produced or concentrates fed were calculated from the figures of Morrison [6]. The dry matter of the hay was assumed to contain 50 per cent. T.D.N. The figure suggested by the Joint Committee [4] for dry hay with 15 per cent. moisture and 9 per cent. ash is 60 per cent.

The yield of crude protein per morgen was calculated from the total nitrogen return multiplied by 6·25.

All animals were weighed for 3 consecutive days at the beginning and end of the grazing season and every 28 days throughout the experiment. Averages of the three weighings were recorded.

Results in the 1949–50 Season

After a trial period of 2 months two groups of six animals each were selected from the experimental herd. These two groups were as similar as possible in all respects. One group was put to graze on 4 morgen of veld receiving a dressing of N_3P fertilizer; the other group was grazed on 8 morgen of unfertilized (control) veld. All animals in both groups were fed 3 lb. of concentrates per day per head throughout the grazing-season. Grazing was limited to two periods per day: from 7.30 a.m. until noon, and from 6 p.m. until 6 a.m. During the heat of the day the cows were put on a shaded plot where there was no grazing at all. Unfortunately, owing to difficulties in obtaining apparatus and reagents, butter-fat tests were made only twice during this season. However, there seemed to be only small differences in the percentages recorded, so an average percentage butter-fat content was used in the calculations.

The following are the monthly rainfall figures for the grazing period (in.): 1949, Dec. 6·89; 1950, Jan. 2·60, Feb. 2·62, Mar. 3·18, Apr. 2·13, May 1·64. Total for 6 months, 19·06 in.

The experiment started on Dec. 1, 1949, and the plots were closed for the winter on May 9, 1950, a total of 160 grazing-days.

TABLE 1. *Group Production per morgen in lb. Milk*

	Control group	*N_3P group*
December 1949 .	730	1,170
January 1950 . .	682	966
February . . .	426	720
March . . .	401	627
April . . .	314	534
May (9 days) . .	93	186
Total . . .	2,646	4,203

The above results were statistically analysed by 'Student's' method. From this analysis it was clear that the differences between treatments were highly significant ($P = 0{\cdot}01$).

As an alternative method of analysis the production of total digestible nutrients per morgen was calculated.

TABLE 2. *T.D.N. produced per morgen*

Treatment	*Live-weight gained (lb.)*	*Live-weight maint. (tons)*	*T.D.N. (lb.)*	*T.D.N. in milk (lb.)*	*T.D.N. in hay (lb.)*	*Total T.D.N. (lb.)*
None	23	63·8	1,017	513	356	1,940
N_3P	45	127·3	2,135	700	1,232	4,067

Difference due to treatment = 2,127 lb.

Table 3 shows the production of hay per morgen from the two treatments that were not grazed. Also shown are the production of nitrogen, P_2O_5, and soluble ash, and the calculated production of crude protein.

TABLE 3. *Production per morgen from the Areas not grazed*

Treatment	*Hay prod.* (*lb.*)	*N* %	*N* (*lb.*)	P_2O_5 %	P_2O_5 (*lb.*)	*Sol. ash* %	*Sol. ash* (*lb.*)	*Crude protein* (*lb.*)
None	1,620	0·83	13·4	0·19	3·10	1·32	21·4	84
N_3P	2,747	1·14	31·3	0·39	10·7	1·90	52·2	196

Difference = 112 lb.

These figures show that not only has the application of fertilizer increased the production of hay, but also the percentages of nitrogen and P_2O_5, and the amount of crude protein, which has been more than doubled.

Financial returns.—To ascertain these returns as accurately as possible, an average price for milk of 2*s.* 2*d.* per gallon has been used throughout [7].

TABLE 4. *Financial Returns for the Season*

Treatment	*Gals. milk*	*Gross return 2s. 2d. per gal.*	*Less cost of S/A per morg.*	*Less cost of R & S per morg.*	*Less cost of spreading*	*Increase per morg. due to fertilizer*
None	265	£28. 14*s.* 2*d.*	..	..	..	..
N_3P	420	£45. 10*s.* 0*d.*	£7. 7*s.* 0*d.*	£1. 9*s.* 0*d.*	5*s.*	£7. 14*s.* 10*d.*

NOTE. Cost of sulphate of ammonia (S/A), £24. 15*s.* 0*d.* per ton.
Cost of rock and superphosphate mixture (R & S), £7. 4*s.* 6*d.* per ton.

To arrive at the difference due to treatment the gross return from the control group, plus the price of fertilizers, plus the cost of spreading, were subtracted from the gross return of the N_3P group.

Results in the 1950–51 Season

At the suggestion of Prof. W. B. Nevens [8] the experiment was slightly modified before the beginning of the grazing season. From the records up to date the cows were 'paired off' in such a way that the individuals in each pair were as nearly identical as possible in all respects. One cow from each pair was put into the N_3P group, the other was into the 'None' group. To avoid any unfair bias the final selection into groups

TABLE 5. *Amounts of Concentrates fed to each Pair during the Grazing Season*

Pair	*Concentrates fed per head per day* (*lb.*)				
	December	*January*	*February*	*March*	*April*
1	8	8	5	3	3
2	5	5	3	3	3
3	8	8	5	3	3
4	3	3	3	3	3
5	5	3	3	3	3
6	10	10	8	5	3

was done by someone unacquainted with the experiment. Each pair of animals was then fed a concentrate ration according to the pair's production. In this way it was thought that a fairer assessment of the value of the grazing could be obtained.

As during the 1949–50 season, there were two groups of six animals. The fertilizer treatments were the same as in the previous season, and also the length of daily grazing periods.

The following were the rainfall figures for the months during which grazing took place (in.): 1950, Dec. 7·68; 1951, Jan. 3·97, Feb. 2·16, Mar. 2·60, Apr. 2·22. Total for 5 months, 18·63 in.

As these figures show, there was a relatively dry spell during February and March, but the rainfall for December and January was above average. These great fluctuations in rainfall no doubt accounted for the comparatively poor growth made by the herbage.

As a result of this poor season there was no surplus hay to be mown from the control plots, but in the N_3P treatment the growth during January was so vigorous that the six animals could not keep pace with it. It was decided, therefore, to close 1 morgen of this treatment temporarily and to graze only 3 morgen. This 1-morgen plot was closed on Jan. 15 and reopened for grazing on the Feb. 28, after it had been mown, and the hay weighed and credited to the N_3P treatment in terms of lb. total digestible nutrients. (Air-dried hay was assumed to contain 50 per cent. T.D.N. (see Table 7).)

The grazing season began on Dec. 1, 1950, and the plots were closed again for the winter on Apr. 20, 1951: a total of 141 grazing days.

TABLE 6. *Group Production per morgen in lb. Milk*

	Control group	*N_3P group*
December 1950 .	706	1,406
January 1951 . .	645	1,307
February . . .	490	1,019
March . . .	424	887
April (20 days) . .	281	476
Total . . .	2,546	5,095

The above results were statistically analysed by 'Student's' method. This analysis showed that the difference between the two treatments was highly significant ($P = 0{\cdot}01$).

Butter-fat tests were done at monthly intervals throughout the season except in January, when reagents were unobtainable. There appeared to be no differences in percentage butter-fat due to treatment, and the average percentages of the groups over a period of 5 months, November to April, were 3·8 per cent. for the N_3P group and 3·9 per cent. for the control group.

The data collected were again converted into lb. of total digestible nutrients produced per morgen, using the same equations as in the previous season.

TABLE 7. *T.D.N. produced per morgen*

Treatment	*Live-weight gained (lb.)*	*Live-weight maint. (tons)*	*T.D.N. (lb.)*	*T.D.N. in milk (lb.)*	*T.D.N. in hay (lb.)*	*Total T.N.D. (lb.)*
None	19	55·4	928	341	..	1,269
N_3P	64	110·2	1,935	692	970	3,597

Difference due to treatment = 2,328 lb.

Hay production during the season was exceptionally poor on the plots set aside for mowing only. The differences in yield between the grazed and the mown plots might be ascribed to the fact that whilst there was only one mowing possible during January on the hay plots, there was new growth after this period, but not sufficiently vigorous to warrant mowing. It is probable that the same amount of growth took place on the grazing plots, but in this case it was sufficiently vigorous to stand up to grazing.

As usual, samples were taken of the hay when it was weighed, but unfortunately the chemical analysis of these samples is not yet to hand. The yields of air-dry hay per morgen from the two treatments were: None (mown), 775 lb.; N_3P (mown), 1,050 lb.

TABLE 8. *Financial Returns for the Season*

Treatment	*Gals. milk*	*Gross return 2s. 2d. per gal.*	*Less cost of S/A per morg.*	*Less cost of R & S per morg.*	*Less cost of spreading*	*Increase per morg. due to fertilizer*
None	255	£27. 12s. 6d.	..	..	..	..
N_3P	510	£55. 5s. 0d.	£7. 5s. 0d.	£1. 10s. 6d.	5s.	£18. 12s. 0d.

NOTE. Cost of sulphate of ammonia, £24. 3s. 6d. per ton.
Cost of rock and superphosphate mixture, £7. 12s. 0d. per ton.

Discussion

Two years' experimentation with dairy animals on fertilized veld have confirmed many of the results of other fertilizer experiments previously published.

The average yields of total digestible nutrients for the two treatments, 'None' and N_3P, as shown by Hall *et al.* [2], compare favourably with the yields of these treatments as shown in this experiment.

TABLE 9. *Comparison of Yields of T.D.N. in Experiments with Beef Steers and Dairy Cows*

Treatment	*Average yield of T.D.N. per morg. in expt. with beef steers*		*Yield of T.D.N. per morg. in expt. with dairy cows*	
None	1937–49	1,215 lb.	1949–50	1,940 lb.
			1950–1	1,269 lb.
N_3P	1937–49	3,197 lb.	1949–50	4,067 lb.
			1950–1	3,597 lb.

In spite of the very high price of sulphate of ammonia the fertilizer treatments have been financially remunerative. Should the cost of nitrogenous fertilizer decrease in the future even greater returns can be expected.

The data presented here will most probably be of more value to the dairy farmer who has only small pastoral lands and has to buy the bulk of his roughage feeds. To this type of farmer the great increases shown in carrying capacity and feeding-value of fertilized veld can directly affect his cost of milk production, and therefore increase his profit margin.

It seems apparent that the economic upper limit of nitrogen application has not been reached with 600 lb. of sulphate of ammonia per morgen. Theron [9] has shown that with dressings up to 4,000 lb. per morgen the percentage protein is still being increased. From a dairying point of view this increase is important, as it will probably result in a further increase in milk production per unit area.

Summary

1. The results obtained in a fertilizer experiment on natural veld over two seasons are given in this paper. Dairy cows were used as grazing animals and the results are quoted in lb. of milk produced per morgen. From these figures and the live-weight gains per morgen, the live-weights maintained and the yield of total digestible nutrients per morgen have been calculated.

2. The differences in milk-yields per morgen between the control and fertilizer groups were highly significant.

3. There was a large increase in the yield of total digestible nutrients owing to the application of fertilizer.

4. Despite the high cost of fertilizer there was a substantial increase in financial returns owing to the fertilizer applied.

5. From tests done it is apparent that the application of fertilizers to natural veld does not in any way affect the percentage of butter-fat in the milk.

6. The plots set aside for mowing showed that the fertilizers caused a substantial increase in bulk yields per morgen and in the nitrogen and mineral contents of the herbage.

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VEGETATIVE PROPAGATION OF CABBAGE AND ALLIED VEGETABLES

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WITH PLATE I

THE breeding and maintenance of good strains of cabbage, broccoli, Brussels sprout, and other forms of *Brassica oleracea* present one of the most difficult problems with which the vegetable-seed industry has to contend. At present, improved strains of these vegetables are raised, and the best of the existing strains are maintained, almost without exception, by a simple process of mass selection. The success achieved by this method, whether the object be to improve or to maintain a strain, depends largely on the personal 'flair' of the selector. A satisfactory technique for the vegetative propagation of chosen plants would be a valuable tool in the hands of the experienced selector; it could help him in the following ways:

(*a*) *Overwintering of selected plants.* It is generally accepted that stock-seed plants should be selected under growing conditions similar to those required for the market crop, but this prerequisite may make it difficult to obtain seed from the chosen plants. The Italian types of broccoli, for example, are grown in Britain to produce curds in October or November, but plants selected at this time of the year often die during the winter without setting any seed. Plants that have been selected in the autumn may be propagated vegetatively so that the resultant clones, when planted in the open the following spring, will form curds early in the summer and produce a crop of seed before the onset of adverse weather conditions.

(*b*) *Proving of selected plants.* The excellent qualities of a chosen individual may be due primarily to especially suitable growing conditions, and seedlings from such a plant can often give poor results when raised under average conditions. Selected plants may be propagated vegetatively and the clones grown under a variety of environments. In this way it is possible to make a re-selection of the original plants based on their tolerance to diverse growing conditions.

(*c*) *Permanent maintenance of selected plants.* Periodic re-selection, calculated to prevent deterioration, generally leads to a change in the characteristics of a strain, although this change is sometimes so slow that it is practically imperceptible. This state of affairs makes it difficult for the market-grower to choose the strain most suited to his requirements. Even if he bases his choice on the results of an official yield trial he may find that the recommended strain, although it bears the same name, has changed in character since the conclusion of the trial. For the same reason it is strictly correct to accept a strain as a standard for a yield trial only for as many years as the original stock of seed remains viable. Complete continuity of strain is assured if a nucleus

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of stock-plants is propagated year after year by vegetative means; assuming of course that there is no vegetative mutation with possible selection of the new mutant strain and selective elimination of the original strain.

Vegetative propagation, in addition to its advantages as an adjunct to mass selection, offers attractive possibilities for the formulation of improved methods of breeding cabbages and related vegetables, and this aspect has been dealt with in some detail by Wellensiek [1] and Sneep [2]. Techniques for vegetative propagation should also be of value in the study of factors influencing the curding of broccoli and the heading of cabbage, and other fundamental physiological problems relating to the species.

In recent years research workers in America and Holland have made advances in the study of the propagation of *B. oleracea* by vegetative means, but there still remains a wide field for the devising of suitable techniques for many varieties. During the last 18 months, work on the subject has been in progress at the National Institute of Agricultural Botany.

Healthy, green leafy parts of *B. oleracea* generally develop roots without difficulty under hygienic conditions, and the problem resolves itself into one of the production of material suitable for cuttings. The most useful sources of material fall into three classes: (*a*) plants that have been maintained in a vegetative condition; (*b*) adventitious shoots arising from root-cuttings; and (*c*) adventitious shoots arising from callous tissue induced on stems.

(*a*) *Plants that have been maintained in a vegetative condition.* The various forms of *B. oleracea* pass through two distinct phases, the vegetative and the reproductive; the latter culminating in seeding and the death of the individual plant. The change-over to the reproductive phase may not be apparent from a casual examination, but cuttings taken from a mother plant which has passed into this stage generally produce small plants that flower prematurely, and are therefore of little value to the selector. For practical purposes it is frequently necessary to remove cuttings from plants which, had they been allowed to develop in the open, would have passed into the reproductive stage. In these circumstances it is essential to be able to suppress flowering. Miller [3] has shown that this may be effected with cabbage by keeping the plant in a greenhouse at a temperature of 60°–70° F., and Wellensiek [4] quotes similar results for Brussels sprout.

If plants of the biennial forms of *B. oleracea* are lifted from the open ground in early autumn and brought into a heated greenhouse they may be prevented from passing into the flowering-stage, and cuttings derived from them, when planted in the open the following spring, will continue to grow vegetatively.

A technique for the propagation of Brussels sprout employing this principle has been evolved at the National Institute of Agricultural Botany. Selected plants are taken into the greenhouse during October, and kept at a temperature above 60° F. During the winter the 'buttons' are cut off in such a way that each leaves a stump $\frac{1}{4}$–$\frac{3}{4}$ in. long. Side

shoots grow from the buds on these stumps and may be struck as cuttings. Leaf-bud cuttings, taken when the lamina has grown to a length of 1–2 in., form roots very readily (Plate 1, fig. 1) and permit a greater rate of multiplication than is possible by using the shoots themselves. As many as 277 clones derived from leaf-bud cuttings have been obtained from one individual mother plant in this way. The cuttings are capable of growing into full-sized plants which produce normal 'buttons', and flower and seed the following year.

Promising results have been obtained with a similar method for the propagation of cabbages.

(*b*) *Adventitious shoots arising from root-cuttings.* Isbell [5] has shown that cabbages may be reproduced by root-cuttings. A modification of his method has been used in which carefully washed portions of root are planted upright in sterilized sand and kept at 60°–70° F. After 6–8 weeks the adventitious shoots are removed and set as cuttings in a propagating case. They root and are ready for transferring to pots within 10 days.

It has been observed that root-cuttings, even when they are taken from a plant which has passed into the reproductive stage, produce shoots which are in a vegetative condition. Root-cuttings, therefore, provide a useful means of rejuvenating broccoli and cauliflower, which must be selected when the curds are fully developed and have, therefore, entered into the reproductive phase.

We have found this method to be particularly promising also for the reproduction of Brussels sprout and marrow-stem kale. The propagation of some brassica plants by root-cuttings presents difficulties which we have not yet been able to overcome but to which we are devoting especial attention.

(*c*) *Adventitious shoots arising from callous tissue induced on stems.* As long ago as 1930 Graham and Stewart [6] recorded that they had been able to induce isolated portions of broccoli curd to develop roots and to flower. From similar experiments we have found that a slight modification of this method provides a useful technique for the vegetative multiplication of this form of *B. oleracea*.

Mature, undamaged curds are selected and cut from the stumps as they would be for market. They are divided into four or six pieces longitudinally in such a manner that each piece has a portion of leaf attached. The prepared portions are treated with growth-substance by dipping the bases into a shallow dish of 50 per cent. alcohol containing 1,000 p.p.m. indolyl-butyric acid. Immediately after treatment the portions of curd are planted separately in 5-in. flower-pots containing a 2-in. layer of sterile sand over John Innes potting compost. After 7–10 days in a propagating case the portions of curd have formed roots and are transferred to a greenhouse kept at 60° F.

If the flowers have been pollinated satisfactorily the curd portions will carry a crop of seed. Within 2 months from the time of insertion (Plate 1, fig. 2) adventitious buds arising from the callous tissue at the base of the curd portion begin to push their way above the surface of the sand. A few shoots may arise from the cut surface of the curd above the

medium, and even from aborted flowering tissue. When the shoots have reached a size suitable for cuttings they should be removed and set in a propagation case. The regular removal of shoots encourages continued production of propagating material.

As many as forty clones have been derived from one curd in this manner. Most of the clones develop into plants which are in a vegetative condition, but a small proportion may flower prematurely.

Unforeseen obstacles will no doubt arise as we gain further experience in the vegetative propagation of brassicas, but sufficient advances have already been made to justify its inclusion in the planning of schemes for the improvement of Brassica strains.

Summary

Some aspects of the application of vegetative propagation to the improvement and maintenance of brassica strains are discussed. The vegetative propagation of *B. oleracea* is largely a problem of obtaining suitable material for cuttings. Three methods of producing this material are described, with special reference to work in progress at the National Institute of Agricultural Botany.

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FIG. 1. Leaf-bud cuttings of Brussels sprout 10 days after planting in propagating case. (Scale in cm.)

FIG. 2. Rooted portion of broccoli curd showing flowering and seeding stems and growth of adventitious shoots.

STUDIES ON THE FERTILITY OF GOLD COAST SOILS

Pt. III. THE PHOSPHATE STATUS OF THE SOILS

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In the programme of fertilizer trials described in Part I of this series (this J., 1951, **19**, 202), superphosphate was one of the treatments in all trials. The yield responses of the different test crops are summarized in this paper and related to the soils, their natural vegetation and past usage. The effect of different rates of application of superphosphate, which was tested in the second year, is also described.

The soil samples that were taken from each trial site have been analysed for 'adsorbed' phosphate and for 'acid-soluble plus adsorbed' phosphate, and the extent to which these values are correlated with the crop responses to superphosphate has been determined.

Responses to Superphosphate

The crop responses to a dressing of 2 cwt. per acre of superphosphate in all the trials are summarized in Table 1.

There are interesting differences in the responses between the various climate and soil groups.

In the forest and southern fringing forest, the difference between the responses on the undisturbed and the disturbed sites is very clear both for maize and cassava.

In the savannah, on the Voltaian soils, a comparison between the percentage responses of maize, guinea-corn, and yams on sites recently cropped after a long period of rest in bush, and those which have been cropped more frequently, suggests that there is a rapid release of phosphate from the organic matter that has accumulated during the long resting-period and that this is sufficient to maintain the crop. (Groundnuts are exceptional for reasons that will be considered below.)

On the granite soils of the far north, where cropping is continuous, the highest percentage responses of any region are obtained. The order of the responses agrees with certain points of farming practice in the far north. Early millet appears as a relatively high fertility crop, and it is grown only on the compound farms. Dung is usually applied to the mixed early-millet and guinea-corn crops, which are more responsive than mixed early millet and late millet or groundnuts.

The order of response of the guinea-corn and late millet on the greenstone soils is similar to that on the granite.

In nearly all the trials, a significant response to superphosphate was accompanied by a significant increase in growth in the first month.

Interaction between nitrogen and phosphate.—The values of the interaction between nitrogen and phosphate for all the trials are included in Table 1, which shows the average interaction for the different crops in

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TABLE 1. *Phosphate Responses and Nitrogen × Phosphate Interactions*

	Response to 2 cwt. per acre superphosphate						*Nitrogen response mean %*	*Nitrogen × phosphate interaction mean %*
	No. of trials with positive effects		*negative effects*		*Total no. of trials*	*Mean response %*		
	sig. at P = 0·05	not sig.	sig. at P = 0·05	not sig.				
1. Forest and southern fringing forest: (*a*) undisturbed sites*								
Maize (1)	5	4	0	0	9	21	3	−3
Maize (2)	1	2	0	0	3	29	−5	−7
Cassava	0	3	0	0	3	13	3	3
(*b*) disturbed sites								
Maize (1)	0	4	0	3	7	1	1	0
Cassava	0	1	0	3	4	−9	3	0
Groundnuts	0	2	1	0	3	−3	−2	0
2. Savannah. Voltaian soils: (*a*) long resting-period sites								
Maize (1) and (2)	3	4	1	0	8	11	42	1
Guinea-corn	3	2	0	1	6	11	26	2
Rice	0	1	0	0	1	(10)	(41)	(39)
Sunflower (1) and (2)	2	2	0	0	4	13	19	−6
Cassava	0	0	1	1	2	−9	11	5
Yams	1	2	0	2	5	0	11	2
Groundnuts	6	2	1	4	13	12	9	−8
(*b*) short resting-period sites								
Maize	6	3	0	1	10	19	17	5
Guinea-corn	5	2	0	0	7	29	24	7
Late millet	0	3	0	0	3	15	13	4
Yams	0	5	0	1	6	8	10	8
Groundnuts	2	1	0	4	7	4	−9	−5
3. Savannah. Northern granite soils								
Guinea-corn†	6	2	0	0	8	38	19	11
Late millet†	3	3	0	0	6	13	26	9
Early millet‡	5	1	0	0	6	70	31	28
Groundnuts	3	3	0	0	6	17	−4	−2
4. Savannah. Greenstone soils								
Guinea-corn	2	0	0	0	2	33	17	17
Late millet	0	1	0	0	1	10	38	−5
All sites								
Maize	15	17	1	4	37	13	14	0
Guinea-corn	16	6	0	1	23	28	22	8
Late millet	3	7	0	0	10	13	24	7
Early millet	5	1	0	0	6	70	31	28
Rice	0	1	0	0	1	(10)	(41)	(39)
Sunflower	2	2	0	0	4	13	19	−6
Cassava	0	4	1	4	9	2	5	2
Yams	1	7	0	3	11	3	11	4
Groundnuts	11	8	2	8	29	10	1	−5

* See Part I for an explanation of the grouping of the sites.
† 3 trials mixed with early millet.
‡ All trials mixed with late millet or guinea-corn.
(1) First season. (2) Second season.

each climate and soil group, together with the mean nitrogen and phosphate effects. With the exception of groundnuts, the interaction is not appreciable except under conditions when both the phosphate and the nitrogen main effects are high. In the far north the interactions for early millet and for guinea-corn are greater than 10 per cent., and on the frequently cropped sites of the Voltaian they are greater than 5 per cent. for maize, guinea-corn, and yams. In all these instances the nitrogen and phosphate effects themselves are high, particularly on the early millet.

Effects of superphosphate on groundnuts.—Table 1 shows that there is in general a negative interaction between superphosphate and sulphate of ammonia on groundnuts. This is particularly marked on sites very deficient in nitrogen, which, as explained in Part II (this J., 1951, **19**, 275), are the sites on the Voltaian soils planted after a long period of rest.

The nitrogen and phosphate main effects and their interaction for each of the trials on groundnuts on the long resting-period sites are shown in Table 2.

TABLE 2. *Nitrogen and Phosphate Main Effects and Interactions on Groundnuts—Long Resting-period Sites*

Site	*Main effect*		*Interaction*
	Nitrogen %	*Phosphate* %	*Nitrogen × phosphate* %
1948			
Ejura 2 .	−2	9	−6
Kassei 1 .	32*	18*	−22*
Yendi 3 .	3	24†	−23†
Damongo 1 .	10†	25*	−16*
1949			
Ejura 5 .	10*	10*	−1
Kassei 1 .	1	−10	−7
Kassei 2 .	4	1	4
Damongo 2 .	13†	38*	−21*
Ejura 6 (1) .	3	−8	11
Ejura 6 (2) .	−5	−21†	−10
Kassei 4 (1) .	7	−1	−1
Kassei 4 (2) .	6	−4	7
Damongo 7 .	4	29*	−8
Mean . .	9	12	−8

* sig. at P = 0·01. † sig. at P = 0·05.

The five sites on which groundnuts were taken as the first crop immediately after clearing were Kassei 1, Yendi 3, Damongo 1, Damongo 2, and Damongo 7, and these all show high negative interactions. On these sites the leaves on plots receiving no sulphate of ammonia or superphosphate were yellowish throughout the growing period. The addition of lime had no effect on the appearance. However, plots

receiving not only sulphate of ammonia but also superphosphate had a healthy green colour.

This effect is specific to groundnuts, for maize and guinea-corn show a positive rather than a negative interaction between sulphate of ammonia and superphosphate when growing on sites seriously short of available nitrogen, and superphosphate causes no improvement in the yellowish colour of the leaves, though of course sulphate of ammonia does.

The author has recently seen experiments being conducted in northern Nigeria[1] in which gypsum is dusted on the leaves of groundnuts. This causes an improvement in the foliage similar to that caused by an application of superphosphate, so that it appears that the calcium sulphate component of the superphosphate rather than the phosphate component is effective. The most likely explanation of the phenomenon is that soluble calcium or sulphur released by the gypsum is improving the nitrogen status of the groundnut plants, probably by an effect on the root-nodules. The solubility of gypsum is considerably greater than that of lime, which would explain the inefficiency of lime if calcium is the stimulant.

Anderson and Spencer have recently reported that sulphur has stimulated nitrogen utilization in clover on nitrogen-deficient soils in New South Wales [1].

It may be mentioned, in view of evidence from the United States that the addition of gypsum may increase the shelling percentage of the nuts, that in these trials the shelling percentage was about 70 per cent., and superphosphate had little effect on this figure. The effect can hardly be on the general soil-nitrogen bacteria, for crops other than groundnuts would then show the beneficial effects of superphosphate on their leaves.

It will be noted from the figures given in Table 1 that superphosphate has little effect on groundnuts on the Voltaian soils so long as the nitrogen status of the soil is satisfactory. This is shown by the effect P+NP. Phosphate, as such, may not be required, and it is probable that on these soils gypsum will prove as good as superphosphate. However, on the far northern granite soils the negative NP interaction is small, and the response to superphosphate was 17 per cent.

Rate of application of superphosphate.—There were no trials with different levels of superphosphate in the forest, but the savannah areas have been well covered. A summary of the responses to superphosphate at 2 cwt. per acre and 1 cwt. per acre for all soil groups is given in Table 3.

Apart from the yam trials and rice trial, in none of which were there significant responses to phosphate, it appears that the response to 1 cwt. per acre of superphosphate is well over half that of the 2 cwt. per acre dressing. In only two instances did the 2 cwt. per acre dressing give a significant increase over the 1 cwt. per acre dressing.

On the far northern granite soils, where the effects of phosphate are most marked, it will be seen that the 1 cwt. per acre dressing is almost

[1] By courtesy of M. Greenwood.

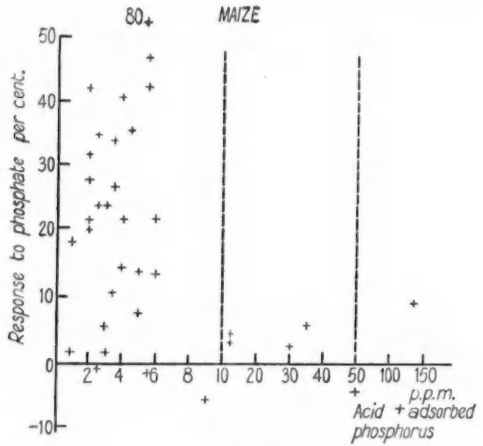
TABLE 3. *Response to Different Rates of Application of Superphosphate*

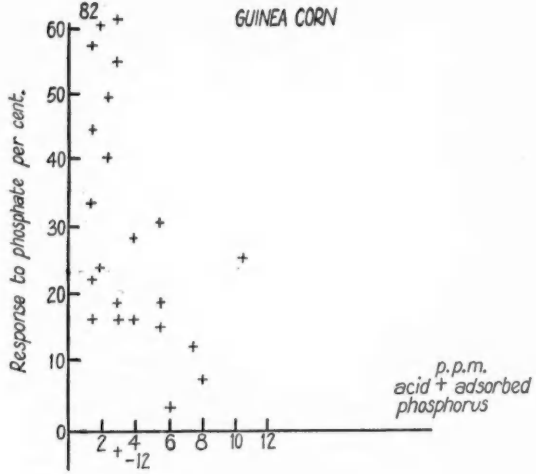
Crop	No. of trials	Response to 2 cwt. per acre superphosphate %	Response to 1 cwt. per acre superphosphate %
Voltaian soils: (*a*) long resting-period sites			
Maize	4	7	3
Guinea-corn	2	8	17
Rice	1	(10)	(2)
Sunflower	2	21	15
Yams	2	3	0
Groundnuts	5	3	12
(*b*) short resting-period sites			
Maize	3	14	13
Guinea-corn	3	30	17
Late millet	3	15	7
Yams	3	7	−3
Groundnuts	3	3	6
Northern granite soils			
Guinea-corn	3	39	25
Late millet	3	12	8
Groundnuts	3	14	12
All sites:			
Maize	7	9	6
Guinea-corn	8	29	20
Late millet	6	13	8
Yams	5	5	−1
Sunflower	2	21	15
Rice	1	(10)	(2)
Groundnuts	11	7	11

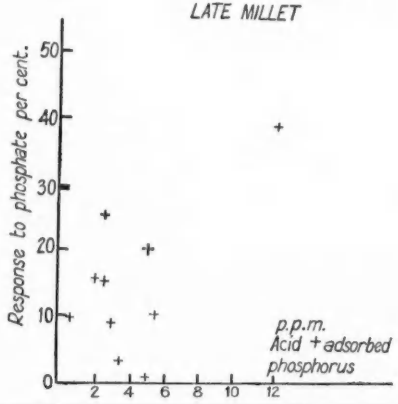
as good as the 2 cwt. dressing for groundnuts and gives well over half the response of the double dressing on guinea-corn and late millet. There were unfortunately no trials on early millet.

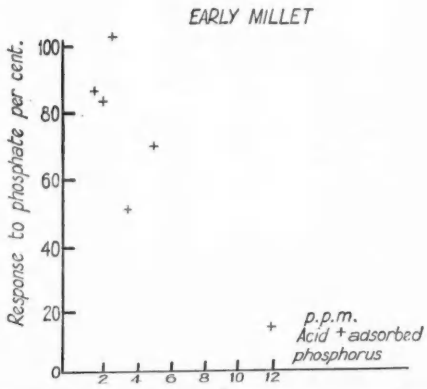
Laboratory determination of the phosphate status of the soil.—An attempt was made to find what correlation could be established between the responses of the crops on each trial site to superphosphate and the laboratory determination of the available phosphate in the soil. Composite samples of the 0–6 and 6–12 in. layers of each trial site were analysed for available phosphate.

The most frequently used method of determining the amount of phosphate in the soil available to plants has been by extraction with dilute acid. More recently the importance of so-called 'adsorbed' phosphate as a supply of phosphate to the plant has been recognized. Adsorbed phosphate is extracted by numerous anions among which the fluoride ion has been used. Bray and Kurtz, whose methods of extraction have been adopted, have found that both groups of phosphate occur on the corn-belt soils in Illinois, U.S.A., and have obtained better correlation of responses to phosphate with the acid-soluble plus


MAIZE
80
Response to phosphate per cent.
50
40
30
20
10
0
-10
2
4
6
8
10
20
30
40
50
100
150
p.p.m.
Acid + adsorbed
phosphorus


GUINEA CORN
82
Response to phosphate per cent.
60
50
40
30
20
10
0
2
4
6
8
10
12
-12
p.p.m.
acid + adsorbed
phosphorus


LATE MILLET
Response to phosphate per cent.
50
40
30
20
10
0
2
4
6
8
10
12
p.p.m.
Acid + adsorbed
phosphorus


EARLY MILLET
Response to phosphate per cent.
100
80
60
40
20
0
2
4
6
8
10
12
p.p.m.
Acid + adsorbed
phosphorus

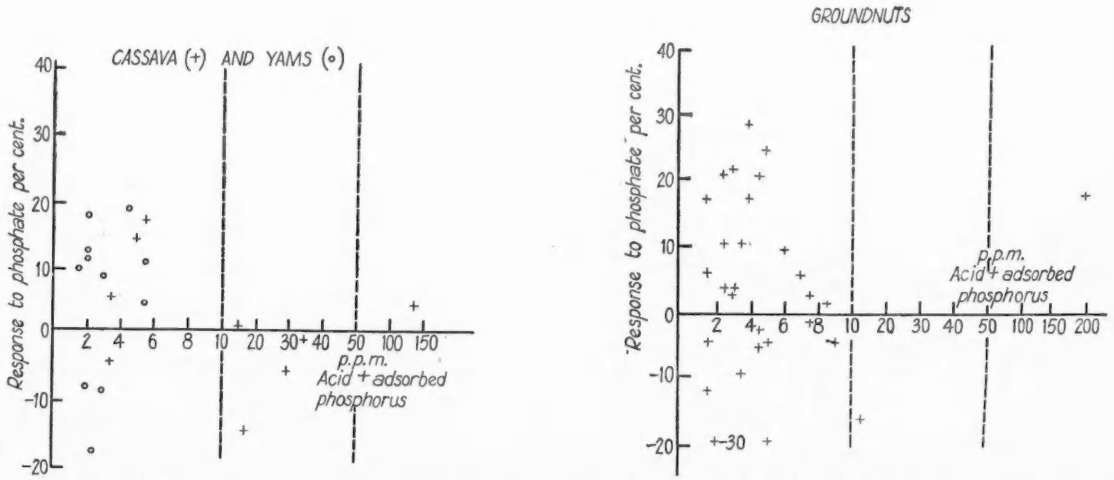


FIG. 1. Correlation of crop responses to 2 cwt. per acre superphosphate with acid-soluble+adsorbed-phosphorus content of the top 6 inches of soil

adsorbed-phosphate values than with the acid-soluble phosphate or the adsorbed-phosphate values alone.

The methods of extraction were as follows. Adsorbed phosphate: Two grams of air-dry soil were shaken one minute with 7 c.c. of a 0·03N solution in ammonium fluoride, and 0·025N in hydrochloric acid. Acid-soluble plus adsorbed phosphate: Two grams of air-dry soil were shaken one minute with 7 c.c. of a 0·03N solution in ammonium fluoride, and 0·1N in hydrochloric acid.

Correlation of crop response to phosphate with acid-soluble plus adsorbed-soil phosphorus.—In the graphs of Fig. 1, the parts per million (p.p.m.) of acid-soluble plus adsorbed phosphorus in the 0–6 in. layer of each site are plotted against the percentage increase in the yield of the various trial crops which results when 2 cwt. per acre of superphosphate is applied. The figure of percentage increase in yield rather than actual increase is used owing to the very wide range of mean crop-yields covered, e.g. maize from 180 to 3,072 lb. per acre. For groundnuts the response to superphosphate includes the effect it has on the nitrogen condition of the plants, as explained above. In order that the phosphate effect alone shall be considered, the response to superphosphate in the presence of sulphate of ammonia, when the nitrogen condition will anyway be satisfactory, is plotted. This is the effect (P+NP).

It will be noted, particularly on the graphs for maize and cassava, that although most of the sites have available phosphorus figures that fall between 2 and 6 p.p.m., there are some with much higher figures falling between 10 and 200 p.p.m. Nearly all of these are the disturbed sites (cf. Pt. I). A group of sites at Kpeve with available-phosphorus figures of over 100 p.p.m. was occupied 50 years ago by a village, and they have since been very frequently cultivated, yet they still have a very high fertility.

None of the sites with more than 10 p.p.m. phosphorus has given responses to phosphate of more than 10 per cent. of the mean yield, with the exception of one trial on groundnuts and one trial on early and late millet. On the undisturbed sites, with less than 10 p.p.m. phosphorus, inspection of the graphs shows that there is no correlation between the response and the available phosphorus in the soil. There is a very wide range in the percentage responses for all the crops.

When similar graphs are plotted of the percentage response against the adsorbed-phosphorus content of the soil the distinction between the disturbed and undisturbed sites is not so clear. A plot against the acid-soluble phosphorus is as useful in distinguishing disturbed from undisturbed sites as a plot against the acid-soluble plus adsorbed phosphorus. For the undisturbed sites neither the acid-soluble phosphorus nor the adsorbed-phosphorus figures separately give any indication of the response to be expected.

On sites with a pH below 6·5 the phosphorus in the adsorbed form was greater than the phosphorus in the acid-soluble form. On sites with a pH above 6·5 there was more phosphorus in the acid-soluble form, particularly on sites known to have been disturbed.

It is an interesting question why some of the cereals on sites with low

available phosphorus nevertheless fail to show responses of more than 10 per cent. to superphosphate, for on the average they show high percentage responses. A high proportion of these sites are on Voltaian soils that have been cropped no more than 3 years since the land was rested for a long period. It has already been pointed out in the discussion of the phosphate responses in Table 1 that the percentage response on these sites is less than on those Voltaian soils cropped more frequently for maize, guinea-corn, and yams, the crops tried under both conditions; and in turn the percentage responses on the continuously cropped granite soils of the far north are greater still. These observations suggest that a release of phosphate from the soil organic matter during the growing period of the crop is very important. Such phosphate would not be determined by the extraction methods used on samples taken at the beginning of the season.

Summary.—High responses to superphosphate are obtained in the forest, particularly on frequently cropped granite soils. In the savannah, the Voltaian soils give moderate responses when they are frequently cropped, but have a satisfactory phosphate status when allowed a long resting-period. On soils seriously short of nitrogen, groundnuts respond to the calcium sulphate in superphosphate which, it is suggested, stimulates the nodules to fix nitrogen. The granite and greenstone soils of the far north show considerable responses to phosphate on all crops. One cwt. per acre of superphosphate will be a more profitable rate of application than 2 cwt. per acre.

The interaction between nitrogen and phosphate is high and positive on cereals in the north, where the nitrogen and phosphate effects themselves are high, but is not appreciable elsewhere, except on groundnuts on soils seriously short of nitrogen. Here there is a negative interaction for the reason already mentioned.

Determination of acid-soluble phosphate has been useful in picking out sites disturbed by their being under or near old villages or camps. The adsorbed-phosphate values are less useful. There is little correlation between these values of 'available' phosphate and the percentage increase in yield given by superphosphate to any of the crops on the undisturbed sites.

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THE CAUSES OF DETERIORATION OF COTTON SEED IN THE EQUATORIA PROVINCE OF THE ANGLO-EGYPTIAN SUDAN

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SINCE 1945–6 the cultivation of American-type cotton (*Gossypium hirsutum* L.) as a rain-grown crop has been encouraged in certain areas of the Equatoria Province of the Anglo-Egyptian Sudan. This province is the southernmost region of the country, and in some areas with suitable soil and climate cotton cultivation can profitably be undertaken [1]. The variety mainly grown now is known as BAR SP 84, a cotton that possesses considerable resistance to blackarm, the destructive rain-spread disease caused by *Xanthomonas malvacearum* (E. F. Sm.) Dowson.

In recent seasons there have been reports of very poor germination of the sowing seed, and, since this might have jeopardized the future of cotton cultivation in the southern Sudan, the subject was investigated. Also, the question of the effect of such deterioration upon the oil-content of the seed was important, because the use of cotton seed for oil production is planned. This paper summarizes the results of investigations carried out in the main cotton-growing areas of the south-west of Equatoria Province during the period 1948–50. It is divided into two sections: (*a*) Loss of germinability due to damage in the field before picking; (*b*) Deterioration during storage.

(*a*) *Field Damage before Picking*

A sample of seed reported to have shown very poor germination gave in a test only 22·6 per cent. germination, and on cutting about 29 per cent. appeared to be normal healthy seeds. The seeds appeared to fall into five main groups:

Group 1. Normal healthy seed. Endosperm smooth, firm, creamy-white with red or black oil spots. The endosperm filled the seed-coat more or less completely and the seeds were of normal size.

Group 2. As in Group 1, but with a distinct yellowish discoloration of the endosperm. This staining often appeared to originate from the side of the endosperm. All stages from a small inconspicuous light-yellow spot to a darker yellow or orange colour pervading the whole of the endosperm were observed. As discussed later, it is likely that this yellowing arises from the punctures made by stainer-bugs (*Dysdercus* spp.) when they feed on the seeds.

Group 3. Endosperm reduced to a brown or black powder: a dry powdery rot of the seed-contents.

[1] Agronomist. [2] Plant pathologist.

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Group 4. Endosperm soft and green or dark brown, not powdery.

Group 5. Endosperm shrivelled, sometimes almost absent, leading to empty seeds. This shrivelling was occasionally accompanied by rotting, but usually not; it may be physiological, the endosperm failing to fill out.

These groups are by no means completely distinct, there being all gradations between them. It is possible that Group 3 is a later stage of Group 2, and that Group 4 includes the 'green' seeds, discussed in Part (*b*), and thought to arise during storage of the seed under conditions of high humidity. Throughout this paper Group 1 is designated 'normal', Group 2 'yellow', and Groups 3, 4, and 5 'rotten' seed incapable of germination. The abbreviations N, Y, and R are used in some of the Tables.

Date of picking.—In December 1948 germination tests were made on samples of cotton from a sowing-date experiment. These samples were of different picking-dates ranging from early October to late December, the sowing-dates being at two-weekly intervals from mid-April to mid-July. The germination tests were carried out on 500 seeds of each sample, each of the five germination dishes containing 100 seeds. Figures given for germination capacity are throughout percentages.

TABLE 1. *Germination Tests in December 1948*

Sowing-date	*Picking-date*	*Germination %*	*Seed %*		
			Normal	*Yellow*	*Rotten*
15.5	8.10	77	72	19	9
..	15.10	80	77	18	5
..	21.10	80	78	13	9
..	1·11	67	70	17	13
..	8.11	56	59	26	15
..	16.11	51	52	29	19
..	1.12	47	44	39	17
30.5	16.10	71	77	10	13
..	10.11	52	57	27	16
..	24.11	48	43	40	17
15.6	4.11	56	61	25	14
..	11.11	54	59	28	13
..	16.11	53	49	26	25
..	23.11	58	50	25	25
..	2.12	50	53	30	17
..	11.12	42	51	17	32
..	23.12	25	26	29	45
30.6	13.11	60	57	25	18
..	20.11	53	57	32	11
15.7	29.11	49	46	28	26
..	7.12	49	45	34	21
..	15.12	34	41	26	33
..	23.12	27	21	15	64

The percentage normal seed, as judged visually, corresponds closely with percentage germination. There is a well-marked decrease in viability and in the proportion of normal seeds from the beginning to the end of the picking season.

Isolations for fungi and bacteria were carried out on individual rotted seeds. The seed was first surface-sterilized and then cut open, particles of the rotted endosperm being inoculated into asparagin-agar medium and nutrient agar. Most of the inoculations yielded common saprophytic fungi, in particular *Aspergillus* spp. (including *A. niger* v. Tiegh.) and, to a less extent, *Rhizopus*. Unidentified bacterial colonies also developed. It is likely that rotting is caused by various ubiquitous fungi and bacteria introduced into the interior of the seed when stainer-bugs puncture the seed-coat and feed on the endosperm, i.e. the rotting follows and is a consequence of stainer attack. Observations on diseases and pests attacking the cotton in the experiment described above were made throughout the season. Blackarm (*Xanthomonas malvacearum* (E. F. Sm.) Dowson) and areolate mildew (*Ramularia areola* Atk.) were widespread, but were not responsible for severe damage. Bollworms—mainly pink bollworm, *Platyedra gossypiella* Saunders—were frequent, and were sometimes followed by black rotting of the lint associated with *Aspergillus niger*. Two samples of seed-cotton were collected and examined in mid-December. Badly stained and discoloured cotton gave 18 per cent. germination and 32 per cent. normal seed, whilst for 'clean' cotton the figures were 41 and 46 per cent. respectively.

Helopeltis was general but, although this insect may feed on the boll, it does not, apparently, attack the seeds. In December the cotton was very heavily infested by cotton-stainers (*Dysdercus* spp.). These insects were present in the opened bolls and appeared to be feeding on the ripe seeds, the boll-walls having opened out and dried up. Numerous stainers were found on almost all the cotton bolls, and often within the lint itself. Sacks of seed-cotton picked at this time contained fair numbers of living stainers mixed with the seed-cotton, and no doubt feeding on it. The results are given in Table 2.

TABLE 2. *Stainer Infestation and Rainfall at the Yambio Research Farm, September–December 1948*

	Rainfall mm.	*Stainer infestation*
September . .	164·2	Found occasionally
October . .	180·9	Fairly common
November . .	28·7	Widespread
December . .	Trace	Heavy

Stainer infestation appears to have been associated with climatic factors and with rainfall in particular. Probably the heavy autumn rains favoured breeding on the cotton and thus induced a maximum infestation in the dry hot month of December. The presence of large numbers of stainers feeding on the ripe cotton seed in the opened bolls most

probably affected germination; the results of further experiments to test this hypothesis are described later in this paper.

As there is a progressive decrease in viability of cotton seed with later pickings, it was to be expected that there would be a similar decrease in viability through the ginning season. Samples of seed ginned at dates between December 1948 and May 1949 were examined.

TABLE 3. *Results of Germination Tests on Seed ginned between December 1948 and May 1949*

Date of ginning	*Grade*	*Germination %*	*Seed %*		
			Normal	*Yellow*	*Rotten*
21.12.48	1	74	80	15	5
30.12.48	1	72	72	17	11
5.1.49	1	74	80	11	9
10.1.49	1	60	58	18	24
17.1.49	1	74	76	10	14
20.1.49	1	65	61	19	20
24.1.49	1	62	68	12	20
1.2.49	1	57	61	13	26
7.2.49	1	57	62	18	20
14.2.49	1	50	53	9	38
21.2.49	1	62	66	7	27
25.2.49	3	43	44	8	48
8.3.49	3	45	51	4	45
16.3.49	3	44	47	4	49
24.3.49	1	59	46	12	42
29.3.49	1	62	51	9	40
7.4.49	1	67	51	17	32
3.5.49	2	61	57	10	33

Thus the later ginned seed showed decreasing germination and a higher proportion of worthless seed. This is especially marked with low-grade seed-cotton, which invariably contains much discoloured cotton resulting from stainer and bollworm attack. Further observations were carried out in 1949 and in 1950 (Table 4).

TABLE 4. *Picking-date Experiments in 1949–50*

Picking date 1949	*Germination %*	*Seed %*		
		Normal	*Rotten*	*Yellow*
3.11.49	79	90	3	7
17.11.49	60	59	25	16
26.11.49	60	65	11	24
6.12.49	50	44	37	19
28.12.49	29	34	45	21
1950				
13.11.50	70	74	10	16
24.11.50	67	69	20	11
5.12.50	50	69	16	15
15.12.50	34	46	25	29
3.1.51	30	24	22	54
15.1.51	25	21	25	54

Similar results were obtained as in 1948: a very considerable increase in worthless seed and a reduction in germination capacity as the season advanced, together with a correspondingly increasing stainer-bug population on the cotton.

The high percentage of worthless seed likely to be found in late-picked seed is of importance not only as regards capacity for germination but also from the aspect of oil-content of the seed, which is likely to be reduced if much rotten seed is present.

Samples of cotton seed of grade I and grade III were analysed for oil-content and acidity as percentage oleic acid (Table 5).

TABLE 5. *Germination and Oil-content*

Date of ginning	*Grade*	*Germination %*	*Oil %*	*Acidity as % oleic acid*
10.1.49	1	60	18·25	3·11
17.1.49	1	74	18·35	2·41
7.2.49	1	57	17·59	5·50
21.2.49	1	62	18·27	2·57
8.3.49	3	45	12·84	4·95

The oil-content of the samples analysed roughly followed percentage germination (i.e. percentage normal seed). Thus seed of germination capacity 57–74 contained 17·6–18·3 per cent. of oil, whilst that of germination capacity 45 contained only 12·8 per cent. oil.

Field observations and experiments had indicated very strongly that stainer-bugs were largely responsible for most of the damage to cotton seed in the field. To verify this a cage experiment was carried out. Stainer-bugs were excluded from certain cotton bolls in the field by means of wire cages, and the resulting seed was examined and compared with seed from bolls exposed to stainer infestation.

TABLE 6. *Stainer Cage Experiment*

Treatment	*Caged*	*Picked*	*Germination %*	*Seed %*		
				Normal	*Rotten*	*Yellow*
Control . .	18·10	11·11	83	90	10	0
With stainers .	18·10	11·11	51	44	28	28
Control . .	11·11	29·11	60	65	9	26
With stainers .	11·11	29·11	28	30	13	57

The results of this experiment, and of the field observations and experiments recorded above, support most strongly the belief that the marked decrease in capacity to germinate and increase in proportion of worthless seed accompanying late picking of cotton in Equatoria are due largely to stainer-bug infestation of the open bolls in the field. The insect in puncturing the seed-coat before feeding on the seed would almost certainly introduce, or facilitate the entry of, various ubiquitous

fungi and bacteria into the interior of the seed. These micro-organisms could under favourable circumstances initiate rotting of the endosperm with subsequent death of the seed and reduction in its oil-content. The yellow and restricted discoloration of the endosperm would appear to be the first stage in this process. Recommendations for preventing this damage are given at the end of this paper.

Flotation in water as related to germination capacity.—During the work described in this paper it became desirable to determine to what extent the ability of delinted seed to float or sink in water could be regarded as an accurate index of capacity to germinate. This method is here referred to as 'flotation'. Samples of BAR SP 84 seed of various picking-dates and ranging in germination capacity from 20 to over 80 were used. Each sample (200 seeds) was delinted in concentrated sulphuric acid for a few minutes, care being taken to ensure that delinting was complete. The seeds were then thoroughly washed in water and finally placed in a large jar of water. The seeds which floated on the surface ('floaters') and those which sank ('sinkers') were counted and were then planted out in germination dishes, percentage germination being determined after seven days.

TABLE 7. *Germination Capacity by the Flotation Method*

Germination %	*Sinkers* %	*Germination %*	
		Sinkers	*Floaters*
84	68	92·6	62·8
76	72·5	89	41·8
74	56·5	75·5	71·9
68	56	75·9	58
66·5	63	86·5	32·4
63	58	87·1	41·7
61	57·5	76·5	40
60	60	75	37·5
59	57	67·5	47·7
58·5	59	70·3	41·5
55·5	55	73·6	32·2
55	57·5	84·5	15·3
51	69	55·1	41·9
50	51·5	71·8	26·7
48	52	67·3	27·1
38·5	43	65·1	18·4
20·5	22·5	51·1	11·6
	Mean	74·35	38·12

Thus most of the results found by flotation tallied closely with those determined by germination tests. Especially was this so with seed of lower germination capacity (below about 60). In some cases, however, there were considerable discrepancies between the results obtained by the two methods. It is apparent that by no means all seeds which sink are viable and, vice versa, not all floaters are worthless. Nevertheless, the percentage of viable seed among seed which sank was about twice

that among seed which floated. The fact that some sinkers did not germinate whilst some floaters did germinate to some extent resulted in the percentage germinations as determined by the two methods being approximately similar. In samples of seed with high germination power the flotation germination was usually lower than actual germination: this suggests that in such seed there is a considerable amount of good seed that floats. In seed of poorer germination capacity (less than about 60) the flotation germination approximated to actual germination to a remarkable degree except in one sample: this suggests that a higher proportion of the floating seed was worthless and a higher proportion of the sinking seed viable.

It is concluded that use of the flotation principle as a method of separating good seed from bad would be of limited application. Considerable separation could be achieved and the percentage germination of any given sample of seed could thereby be increased; but it would be a wasteful process, and a less troublesome method would lie in increasing the sowing-rate to compensate for poor germination of the seed.

(*b*) *Deterioration of Cotton Seed in Storage*

In addition to, and quite apart from, injury to seed caused by heavy stainer infestation it was thought that seed might deteriorate if stored unsatisfactorily: humidity of storage might be an important factor.

Humidity of storage.—In a preliminary experiment cotton seed was subjected to three methods of storage: (i) with free exposure to the air; (ii) in an air-tight jar with low relative humidity; (iii) in an air-tight jar containing a tube of wet cotton-wool to maintain a high humidity. During this experiment the average monthly maxima and minima of temperatures were in the ranges 30–35° C. and 17–20° C. respectively.

TABLE 8. *Results from the Initial Sampling, after 4 and after 9 Months of Storage*

Sampled:	*5.1.49*				*22.5.49*					*12.10.49*				
Treatment	*GE* %	*N* %	*R* %	*Y* %	*GE* %	*N* %	*G* %	*R* %	*Y* %	*GE* %	*N* %	*G* %	*R* %	*Y* %
(i)	..	..	..	..	61	67	13	19	1	47	14	61	18	7
(ii)	63	69	16	15	70	74	1	20	5	62	59	11	24	6
(iii)	..	..	..	..	40	46	29	21	4	0	0	51	49	0

In treatment (ii) only one green seed was recorded after 4 months and only a negligible proportion of the normal seed showed slight greening. In treatment (i) a light greening of the endosperm was general and 13 per cent. green seeds were recorded. In treatment (iii) there was a high proportion of green seed and much deterioration after 4 months.

After 9 months of storage only 11 per cent. of green seeds were noted in treatment (ii), but the percentage had risen to 61 in treatment (i) with

considerable loss in germination capacity. Seed from treatment (iii) completely failed to germinate and consisted only of Group 4, of which 51 per cent. were green and 49 per cent. of various colours ranging from green-brown to dark brown, and with soft endosperm.

These results suggest that this form of deterioration is closely related to humid conditions during storage.

A similar experiment was carried out at the Gezira Research Farm, Wad Medani. BAR SP 84 seed was stored at three humidities and at atmospheric humidity, and its germinating capacity was determined after 5 and 8 months. The average monthly maxima and minima of temperatures fell within the ranges 34–41° C. and 12–25° C., and temperatures were lowest during the first 3 months.

TABLE 9. *Results of Humidity Tests*

Rel. humidity %	*Germination* % (*500 seeds*)		
	Initial	*After 5 months*	*After 8 months*
Atmospheric	84	72	62·6
0		72·4	56·8
33		82	65·2
76		63·8	43·4

The seed stored at high humidity quickly declined in germinability. The optimum humidity for storage appeared to be about 33 per cent., which appeared to be somewhat better than very dry storage. That the stored seed deteriorated more rapidly in Equatoria than at Wad Medani may have been due to difference in climate, and partly to the cotton seed used at Wad Medani having a higher percentage germination (84) than that used in Equatoria (63).

These results agree with those obtained by Phillis and Mason [2] in the West Indies. They worked with Sea Island cotton seed and found the optimum relative humidity for storage at 24–30° C. to be about 30 per cent. High humidity led to rapid deterioration, and *very* dry storage conditions were not as good as storage at medium humidities. Simpson [3], working with Upland and Sea Island cotton seed in the U.S.A., found that seed during storage deteriorated rapidly if both temperature and relative humidity were high, and that seed kept at low temperatures was tolerant towards high humidity. Moisture-content of the seed was closely related to humidity of the atmosphere in which the seed was stored: seed containing less than about 8 per cent. moisture could be kept viable for many years in air-tight containers even at fairly high temperatures.

Observations were also made on sacks of cotton seed stored on wooden trestles in a thatched grass hut under similar conditions to those at seed-distribution centres. Analyses of samples taken at time of storage and after 4 and 9 months for three representative sacks are given in Table 10.

Examination of the seed revealed a progressive greening of the endosperm, which first appeared in March. All gradations from an almost

TABLE 10. *Results of Storage in Sacks*

Initial:	*5.1.49*				*14.5.49*					*17.10.49*				
Sack	*GE* %	*N* %	*R* %	*Y* %	*GE* %	*N* %	*G* %	*R* %	*Y* %	*GE* %	*N* %	*G* %	*R* %	*Y* %
1	68	74	12	14	66	65	10	20	5	61	11	62	23	4
2	72	72	11	17	65	63	10	23	4	53	39	37	22	2
3	65	70	16	14	54	57	9	26	8	46	11	66	19	4

imperceptible shading to a dark-green colouring of the endosperm were observed. A standard dark green was arbitrarily selected and those seeds conforming to it were recorded as a separate group (listed as *G* in the Table): they averaged 10 per cent. in the examination made in May. After 9 months' storage the percentage of green seed had risen as high as 66 per cent. in one sack, normal seed being only 11 per cent. Germinating capacity had declined in all samples, but not so rapidly as the decline in percentage normal seed as estimated by visual examination.

Further evidence indicated that general greening of the endosperm in stored seed began in March. Periodical samples were taken from a large heap of seed-cotton (i.e. the seed as picked, before ginning) stored in a rain-proof, corrugated iron shed. The sampling period extended from January to April 1949. Some 11–12 per cent. of green seeds were found in the March–April samples: extensive greening of the endosperms was found to be associated with the beginning of the rainy season. It is possible that increasing relative humidity leads to increased moisture-content of the stored seed, and associated with this is a change in metabolism accompanied by greening of the endosperm.

Soft, dark-brown endosperms are commonly found in samples of old seed. This form of deterioration may be related to that characterized by greening of the endosperm, but it ('browning') occurs especially under conditions favourable to heating of the stored seed. A sample of cotton picked in December 1949 was stored, peasant fashion, in a tightly packed basket in conditions conducive to fermentation and heating. It was examined after 18 months and 43 per cent. of the seeds had green or brown endosperms, in all gradations between the two colours. Over half of the seed was rotten, falling into Groups 3 and 5 (see pp. 56, 57).

Our conclusion is that cotton seed steadily deteriorates under certain conditions of storage, of which relative humidity appears to be the most important. This deterioration becomes most rapid with the onset of the rainy season, but it appeared not to be very serious in the normal storage period for cotton seed in Equatoria (January to early June). From the aspect of oil-content, the period of storage should be kept to a minimum. This storage effect is quite distinct from the injury caused to seed-cotton in the field by stainer-bugs as described in the first half of this paper. Our investigations suggest the following recommendations:

1. Seed for sowing should be selected only from Grade I cotton of early picking-date (i.e. from the first markets); such seed is less

likely to be damaged by stainers. Date of sowing is of importance in this respect. Also, it might be possible in some seasons to select sowing seed from areas where stainer infestation has been lightest.

2. Efforts should be made to ensure that the cultivator does not leave his cotton unpicked in the field for long periods. In this way the period during which the seed is liable to field damage (insect attack and exposure to rain and high humidity) can be reduced.
3. Precautions should be taken to ensure that the seed is dry. Not only should the cultivator dry his cotton after picking, but also the ginned seed should be dried before storage. Imperfectly dried seed may be more susceptible to changes in humidity during storage.
4. Sowing seed to be stored in a cool, dry, rain-proof place.
5. Germination tests to be carried out on samples of sowing seed before sowing. As far as is practicable, sacks showing poor germination should be rejected.

Summary

1. It has been shown that heavy infestation of mature cotton by stainer-bugs (*Dysdercus* spp.) can result in severe damage to the seed, the latter showing a greatly increased proportion of worthless seed and a corresponding loss in germinating capacity and decline in oil-content. It is likely that rotting of the endosperm is initiated when the insect punctures the seed-coat before feeding on the seed.

2. The extent of this field damage is closely associated with the degree of infestation of the stainer-bugs on the cotton, and this in turn is related largely to climatic and ecological factors. In Equatoria early picked cotton is likely to be but slightly affected, whereas that picked at the end of the season may be severely damaged.

3. The deterioration of cotton seed, with attendant decline in germinating capacity, which occurs under certain conditions of storage, was investigated. Relative humidity was found to be an important factor and its association with greening of the endosperm is discussed.

4. Recommendations for minimizing stainer-bug damage to cotton in the field and for avoiding seed deterioration during storage are put forward.

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BANANAS IN EAST AFRICA

Pt. II. ANNOTATED LIST OF VARIETIES

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(1) The list is set out by localities, eight in number, in Kenya (2), Uganda (2), Tanganyika (3), and Zanzibar (1), in that order.

(2) For each locality are given two lists, of native and alien varieties respectively (except for Zanzibar where there is no native–alien distinction).

(3) Entries are made by local names arranged in alphabetical order. Where a distinct variety was seen but no name collected it is listed as 'Unnamed'.

(4) Each entry contains the following information:
Name (in italic). (Alternative spelling, if any.)
(*Meaning* of name or ? if unknown—*Language* (abbreviated).)
Usage, as raw, boil (i.e. boil or steam), roast, beer, &c.
Distinctive characters, botanical comments, &c.
Identity or *synonymy* (where known). Sometimes information was not available under all these heads and then the entry is correspondingly short.

KENYA

Kiambu

Native varieties (Kik. = Kikuyu; Kisw. = Kiswahili).

Gatika. Probably the same as Gitigi but the fruit has been reported to be a little shorter.

Gatumia. ('Good woman' or 'short, stunted woman'—Kik.) Woman's banana, the fruits large and used for cooking. The plant is short and stocky. Some say that a man must take it with him when he changes his shamba.

Gitigi (*Githithe*). Woman's banana, usually roasted. Flesh pinkish, stodgy. Very near to Mitahato. Gatika is probably the same.

Mbiri. No information.

Mitahato (*Mutahato*). ('Long' or 'tall'—Kik.) Man's banana eaten raw but also used for very young babies. Otherwise reported to be a woman's banana eaten ripe or cooked or roasted as a safari ration for men.

Muchero. ('A white thing'—Kik.) Probably the same as Munjuu, &c., but different from Muchuru.

Muchuru. ('Man with small ears'—Kik.) Man's banana, probably the same as Ndinuku but said to have slightly more curved fruits than that variety.

Munjuu. ('Half-way colour'—Kik.—reference to the dull yellow colour at ripeness.) Man's banana that keeps well and 'lies heavily upon the stomach' and so used for marching rations. A *balbisiana* or hybrid variety with persistent bracts, the same as Muchero and probably the same as Nyeupe, the name under which the variety is sold on the roadside stalls in the Kiambu reserve. Grows quite well up to 7,500 ft. at Uplands, and said to be one of the only two varieties that do grow well at this altitude (cf. Nduyu).

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Muraru. ('Tall, slender woman'—Kik.) A woman's banana, eaten raw. Near to Gitigi but perhaps the fingers less symmetrically arranged. Said by some, on the other hand, to resemble Ndinuku except that it has a longer fruit, green when ripe.

Muthirire. ('Tall'—Kik.) Woman's banana with fruit like Mutika.

Mutika. ('Small, blunt'—Kik.) Woman's banana, cooked with maize, &c. Plant short; fingers fat, ripening blotchy-yellow; flesh pinkish, stodgy.

Mutore. Said to be like a longer Muraru.

Ndinuku. ('Small thing' or (?) 'small woman'—Kik.) A man's banana with a small sweet fruit that ripens green. Muchuru is another name.

Nduyu. ('Pressed together'—Kik.) A cooking banana with large, spreading fingers said to resemble Gitigi closely. Grows well at high altitude (e.g. Uplands, 7,500 ft. Cf. Munjuu).

Nyakahe. ('Beautiful'—Kik.—after a woman of this name.) Woman's banana, cooked. Flesh soft, pinkish. Resembles Muraru closely.

Nyeupe. ('White'—Kisw.—from the waxiness of the fruits.) Eaten raw but must be fully ripe or overripe or else the flesh is very hard and bitter. Similar to and probably identical with Munjuu (q.v.).

Alien varieties

Guindi. Raw. Plants sold under this name by Mr. Graham Bell were probably Guindy.

Neuse. ('Black'—Kik.) The Red banana. Traditionally Ugandan. A mutant bunch half-red and half-green was seen at Kiambu.

Nyoro. ('Brisk, birdlike'—Kik.—after Mr. Graham Bell.) Raw. Canary or Cavendish banana. Two forms are recognized by the Wakikuyu and said to differ in erectness of leaves and colour of fruit.

Sukari. ('Sugar'—Kisw.) Raw. Plant not seen but fruit bought at Kiambu had slender fingers, thick skin and good flavour and texture, resembling in this Kisukari of Zanzibar and Amani. It was neither Guindy nor Silk nor Sucrier.

Uganda. Cook. A dense bunch of small fingers. Allegedly from Uganda. Not recognized.

Wangae. Raw. A man's banana. Reputedly introduced from the coast. Perhaps Guindy again.

KENYA

North Nyanza District

Native varieties (Mar. = Maragoli; Luny. = Lunyore).

Dinamayugu. ('Sharp when unripe'—Mar.) Raw.

Inamagodo. (Name refers to long male axis—Mar.) Boil or raw. Very like Rikanzavan but said to have a longer male axis though the bunch takes the same time to develop.

Irithwa. ('Bitter'—Mar.—equivalent to the Lunyore 'Lyswa'.) Cook, very bitter when unripe.

Kibute. ('Tightly packed'—Mar.) Raw. Bunches tight with short fingers.

Kisigami. ('Not sour when ripe'—Mar.) Cook or raw. A common and popular variety probably the same as Nyaluo (1).

Lyswa. ('Bitter'—Luny.—equivalent to the Maragoli 'Irithwa'.) Cook.

Ngongia. (Maragoli version of the Ugandan name Gonja.) Cook or raw. Probably the same as one of the Ugandan Gonjas and also Munjuu or Nyeupe of the Kikuyu.

Nyakurambi. ('Long'—Lunyore.) Boil or raw.

Nyaluo (1). ('Belonging to the Luo'—Lunyore.) Cook or raw. The name covers several types, this being a short plant with short fingers and more or less deciduous bracts. Probably the same as Kisigami.

Nyaluo (2). ('Belonging to the Luo'—Lunyore.) Cook or raw. Differs from Nyaluo (1) in being a taller plant with large fingers and persistent bracts.

Rikanzavan. ('Curved or snakelike'—Mar.—a reference, perhaps, to the irregular fingers.) Boil or raw. Tall with large pendulous bunch of irregular, angular fingers, numerous flower-relicts on the male rachis and deciduous bracts.

Alien varieties

Sukari. ('Sugar'—Kisw.) Allegedly introduced from Uganda. Guindy or Silk—probably the latter.

Unnamed. The Red banana.

Unnamed. The Cavendish or Canary banana.

Unnamed. Seen at the Masena Farm. A very tall, slender banana with a long bunch (up to 15 hands) of good shape but with small fingers having a poor flavour and numerous soft, brownish aborted seeds.

UGANDA

KAWANDA AND BUKALASA

Native varieties (Lug. = Luganda; Kisw. = Kiswahili).

Bagandeseza. ('They have made me leave my bananas'—Lug.) Boil. Probably Namwezi.

Buzidume. ('He-goat'—Kisw.) Boil.

Gonja. (Collective name for roasting varieties—Lug.) Roast. A *Balbisiana* variety with persistent bracts, which might be Munjuu or Nyeupe of the Kikuyu. Susceptible to weevil.

Gonja (red). Stems and midribs flushed with red but said to be otherwise an ordinary Gonja.

Kabula. (Lug.) Beer. Compound tepal deeply lobed—a very distinctive character. Very common in Mengo (Agric. Dept. Rept.).

Kafuba. ('Big chest'—Lug.) Boil.

Kafunze. ('Become narrow'—Lug.) Boil.

Kakira. ('Tail'—Lug.) Boil. Resembles Musakala.

Katwalo. ('Small bunch or bundle'—Lug.) Boil. A Gonja (roasting) variety of this name was also reported and is presumably different.

Kibuzi. ('Fat, young goat'—Lug.) Boil. Has notably dark-coloured lower sheaths.

Kigerekyanvubu. ('Foot of a hippopotamus'—Lug.) Boil. Resembles Nakitembe.

Kijozi. (Lusoga—this is Kojozi ('Urine'—Kisw.).) Beer. According to Jameson (personal communication) this is the same as Kivuvu and the second unnamed variety in this list (q.v. below), and is a very common *mubisi* or beer variety in Busoga. Probably the same as or very near to Mkojosi of Moshi, &c., and the similarity of the names is noteworthy.

Kisansa. (Lug.) Boil. Resembles Muvubo.

Kisubi. (Place-name on the Entebbe road.) Beer. A slender plant resembling Guindy; this identification was confirmed by cytological examination in which it was found to be diploid ($2n = 22$). A fairly recent introduction though now adopted as native and of increasing importance as a beer banana on account of a high degree of weevil-resistance.

Kivuvu. ('Grey'—Lug.—a reference to the colour of the fruits.) Beer. According to Jameson (personal communication) this is probably the same as the second unnamed variety in the list (q.v. below) and is a very common *mubisi* or beer variety in Kyagwe.

Lujugira. (Lug.) Boil.

Lusamba. ('I have eaten bananas'—Lug. (slang).) Boil.

Luwata. ('That which peels' or 'rheumatic pains'—Lug.)

Lweunzika. ('Leaning'—Lug.) Boil.

Lwondo. ('Gulf'—Lug.) Probably Nandigobe.

Manjaya. Roast. A Balbisiana variety resembling Gonja, above.

Mbwazirume. ('Let the Mbwa flies (*Simulium damnosum*) bite'—Lug.) Boil. A distinctive variety with red sheaths and midribs and short fingers. Especially common in E. Kyagwe which is a *Simulium* area. Rather resistant to weevil.

Mende. (Lug.) Beer. Common in Bulemezi (Agric. Dept. Rept.).

Mukadealikisa. ('That which breaks itself' or 'The mother will hide her children'—Lug.)

Mukubyakonde. ('One who hits with the fist'—Lug.) Resembles Nakabululu.

Musakala. ('Not closely spaced'—Lug.) Boil. Said to be somewhat resistant to weevil.

Musibampina. ('That which ties itself around a banana leaf'—Lug.)

Muteb'Enyonyi. ('Good at shooting birds' or 'Attacked by birds'—Lug.) Boil.

Muvubo. ('Pipe' (i.e. water-pipe, &c.)—Lug.) Boil.

Nabusa. ('The naked'—Lug.) Boil. Entoke in Toro.

Nakabinyi. ('Bent'—Lug.—probably a reference to the male rachis.) Boil. The male rachis stands out sub-horizontally instead of drooping.

Nakabululu. ('Darkness'—Lug.) Boil, an especially favoured variety in Buganda. The male bud is distinctive, broad and semi-blunt at the tip, with short male flowers 2·5–3 cm. long instead of the usual 4–4·5 cm. Resistant to weevil and a very hardy variety under trial at Kawanda.

Nakabululu Omudugavu. ('Black Nakabululu'—Lug.) Boil. As Nakabululu but with a darker pseudostem; probably a bud-sport.

Nakakongo. ('Standing up' or 'short and tightly packed' or 'on one's head'—Lug.) Boil.

Nakamali. ('Money'—Lug.) Boil. Resembles Lujugira.

Nakasabira. (Lug.) Boil. Said to be common in Teso.

Nakawere. ('Young mother'—Lug.) Boil. Male bracts green externally with purple margins.

Nakibule. (A personal name—Lug.) Boil.

Nakinyika. ('That which amasses'—Lug.) Boil.

Nakitembe. (Na—the feminine prefix; *Kitembe*—the wild banana, i.e. *Ensete*—Lug.) Boil. The male rachis is covered with persistent floral relicts and bracts, hence presumably the reference to the wild banana in the name. One of the commonest varieties in Buganda.

Nakyetengu. (Lug.) Boil. Probably Nakitembe.

Nalubi. (A woman's name—Lug.) Boil.

Nalugolima. ('Tall'—Lug.) Boil.

Nambi. (A personal name—Lug.) Boil. A most peculiar variety with 2–8 (commonly 3–4) fruits per hand and very few (often 0) male bud flowers in the bract, giving the male bud a characteristically 'deflated' cylindrical appearance.

Namoge. No information.

Namulondo. ('Throne' or 'vanilla' or the name of a clan of the Baganda which does not eat mushrooms.—Lug.) Boil. At Kawanda the variety had possible symptoms of a mild mosaic. Probably the same as Nakitembe.

Namwezi. ('Of the moon'—Lug.—referring perhaps to the waxy petiole or paleness of the base of the pseudostem.) Boil. Said to be moderately weevil-resistant.

Nandigobe. (Lug.) Boil. Resembles Rikanzavan from the Kisumu area.

Nasalugiri. (Lug.) Boil. The compound tepal is deeply lobed, suggesting identity with Kabula which, however, is a beer variety.

Ndizabaulu. ('Eaten by bachelors'—Lug.—the skin is said to split readily, thus saving bachelors trouble in peeling the fruit.) Boil. Resembles Nakabululu.

Ndizitem. (? Kisw.) Resembles Sira.

Ndyabalangira. ('Food for Princes'—Lug.) Boil.

Nfuka. ('That which changes' or 'to be defeated'—Lug.) Boil. Closely resembles Namwezi but perhaps has a blacker stem.

Nsowe. ('Bare'—Lug.—perhaps a reference to the narrowness of the leaves on the sword suckers.) Beer. Very susceptible to weevil. Very common in the Masaka District (Agric. Dept. Rept.).

Ntika. ('Help me to carry'—Lug.) Boil. Probably Namwezi.

Salalugazi. ('Cut widely'—Lug.) Boil.

Simbolukono. ('To raise oneself on the arm'—Lug.) Resembles Kafuba.

Sindika. ('Push'—Lug.) Beer. The pink flush on the suckers is characteristic. Said to be slightly weevil-resistant.

Sira. ('Go slowly'—Lug.) Boil. Sheaths and midribs red; bunch neat with large upturned fingers and of pleasant flavour when eaten raw. Said to be very susceptible to weevil. Cytological examination showed it to be triploid.

Sitakange. ('I don't let any of my things go'—Lug.)

Zisu. (Lug.) Beer.

Unnamed. A boiling variety in the collection at Kawanda with purple stems and midribs, fat, pointed fingers, numerous persistent floral relicts and bracts. Said to come from Kyagwe (Mengo District) and probably the same as Lwekilo from Bukoba.

Unnamed. A variety called at Kawanda 'Grey Flats (Sese)' proved to be a strongly-growing *Balbisiana* type similar to Bluggoe or Moko of the West Indies, Mkojosi of Moshi, Koroboi of Zanzibar, &c. A native variety from the Sese Islands, presumably roasted and (?) perhaps to be identified with Nakatensese. According to Jameson (personal communication) it is the same as Kivuvu (Luganda) and Kijozi (Lusoga). The last name is interesting in the obvious resemblance it bears to Mkojosi.

Alien varieties

Malaya. Possibly Gros Michel.

Red Banana. The Green mutant was not seen.

'*Small Type*'. A variety so named in the collection at Kawanda proved to be a slender banana with small bunches and fruits and a little pollen in the anthers. Probably it is a diploid.

Sweet Jamaica. Probably Gros Michel.

Yellow Banana. A small-fruited banana said by Thomas (in Tothill, 1940) to be the most extensively cultivated dessert variety in Uganda and to be used for beer-making. It has peculiar male flowers with a faintly pink compound tepal; six sterile white stamens; and no free tepal.

Unnamed. The Dwarf Chinese, Cavendish, or Canary banana.

UGANDA

Other localities—TORO AND ANKOLE

Native varieties (Lank. = Lunyankole; Lut. = Lutoro; Lug. = Luganda).

Bukumo. (Lank.) Probably Nakabululu. See also Nkunku and Namangulungu.

Enjagara. (Lut.) An important boiling variety in Toro (Agric. Dept. Rept.). Probably Nandigobe.

Enkara. (Lut.) An important beer variety in Toro (Agric. Dept. Rept.).

Enkobe. (Lut.) An important boiling variety in Toro (Agric. Dept. Rept.). Probably Nabusa.

Enzirabahuma. (Lut.) An important boiling variety in Toro (Agric. Dept. Rept.).

Gonja mamba. (Gonja is the collective name for roasting varieties; mamba a lung-fish with protuberant gills—Lug.) Roast. Not seen but said to be found near Fort Portal, and a description closely resembled the Horn or Horse Plantain of the West Indies and Nkonjwa chayaya of Bukoba.

Kyamalindi. A beer variety from the Masaka district mentioned by Masefield (Agric. Dept. Rept.). Could this be Cavendish under one of its Kiswahili names, Kimalindi?

Muziranyama. (Lug.) A beer variety seen in Ankole, the name said to be a synonym of Nzirabahima. Probably Sindika.

Nakatensese. (Lug.) Roast. A Gonja variety from the Sese Islands.

Nalukila. ('Long tail'—Lug.) Boil. Seen at Fort Portal. Probably Kakira.

Namangulungu. (Lug.) The name given in Ankole as a synonym of Bukumo and Nkunku. Probably Nakabululu.

Nameru. (Lug.) Seen in Ankole, the name said to be a synonym of Namukago.

Namukago. (Lug.) The name was given in Ankole as a synonym of Naberu.

Njagate. (Lank.) Boil. Probably Nandigobe (cf. Enjagara, above).

Nkara. (Lut.) A beer variety seen in Ankole.

Nkunku. (Lug.) The name was given in Ankole as a synonym of Bukumo and Namangulungu. Probably Nakabululu.

Nyeru. (Lank.) Beer. Said to be a synonym of Muziranyama. Probably Sindika.

Omwangihali. (Lut.) Beer, an important variety in Toro (Agric. Dept. Rept.).

Tindemwa. (Lank.) Boil. Said to be the same as Nakabululu but probably not.

Alien variety

Sukari. ('Sugar'—Kisw.) Seen in Ankole. Raw or dried unripe for flour. Probably Guindy.

TANGANYIKA

BUKOBA

Native varieties (Kih. = Kihaya)

Lwekilo. ('A disease of nursing mothers'—for which this variety is said to have therapeutic value—Kih.) Boil. A very distinctive variety with deep purple stems and midribs and small, fat fruits. The same as an unnamed variety at Kawanda.

Nchoncho. (From verb Kuchoncha—'to settle a difference'—Kih.) Boil.

Ndibwa (*Ndibwa barungi*). ('The food to eat'—Kih.) Boil, a favoured variety, especially for chiefs and the aristocracy.

Nganda. ('Of Uganda'—Kih.) Boil.

Njubo (*Enjubo*). ('Biggest'—Kih.—from Njubu, the hippopotamus.) Boil. Only one plant was seen and it was very reminiscent of Gros Michel in the field.

Nkonjwa. (From verb Kukonja—'to make ready'—Kih.—food eaten while making preparations for a particular operation or journey.) Roast. A plantain type with a long bunch, the fingers of the upper hands much larger than those of the lower. Mporomoka of Zanzibar.

Nkonjwa Chayaya (*Nkonjwa Kyayaya*). ('Tasteless'—Kih.) Roast. Probably Horse Plantain of the West Indies, Gonja mamba of Uganda, &c.

Nkonjwa Nshansha. ('Tasteless and short'—Kih.) Roast. An unfamiliar variety, not one of the Ugandan Gonjas.

Nkundakundi. ('Makeshift'—Kih.) Beer.

Noya (*Nyoya*). ('Superlative'—Kih.) Boil, a favoured variety.

Nshakara. ('Affluent, prosperous'—Kih.) Boil.

Nshakara (2). ('Affluent, prosperous'—Kih.) Roast. Not the same as the other variety of this name.

Nshansha. ('Short'—Kih.) Boil. Resembles Nandigobe of Uganda.
Nshansha rubiri (*Nshansha mbile*). ('Short and bitter'—Kih.) Beer.
Ntai. (From Mutai, a friend—Kih.—that which helps in time of food shortage.) Beer, often drunk as the unfermented juice.
Ntobe. ('Very short, dwarf'—Kih.) Boil.
Ntundu. (Brought by Batundu—Kih.) Boil.

Alien varieties

Unnamed. A bunch closely resembling that of Gros Michel was seen.
Unnamed. Probably Guindy, rare.
Unnamed. The Red Banana, rare.

TANGANYIKA

Moshi

Native varieties (Kimach. = Kimachame; Kichag. = Kichagga; Kisw. = Kiswahili).

Ilalyi. (Kimach.) Mnyenyeli.
Ifwanaiya. (Kimach.) Ndishi.
Irongwe. (Kichag.) Boil and beer. Irongo is a Kimachame version of the name.
Kiseri. (Kimach.) Boil, raw, beer. As Makifui but fingers said to be smaller and more tightly packed. The name may, perhaps, sometimes be used for Kinguruwe, or it may not even be a good varietal name at all.
Kiseri Ilalyi. (Kimach.) Makifui.
Kitarasa. (Kichag.) Raw, boil. The flesh and latex of the bulb is pinkish-orange and the latter hardly discolours on contact with iron. The latex of the outer sheaths is whitish. Immature fruit has white flesh with orange-yellow latex.
Makifui. ('Shortness'—Kichag.) Raw, boil, bake, beer. Plant semi-dwarf, the top of the bunch usually contained within the pseudostem, bracts persistent. Kiseri Ilalyi in Kimachame dialect. Perhaps Mficha chana of Zanzibar.
Mamweri. (Kimach.) Mshekisheke.
Mbo. (Kichag.) See Msusu.
Mbwe. (Kimach.) Msusu.
Mchare. (Kichag.) Raw, boil, bake. A common and important variety. Nshonowa in Kimachame.
Mkojosi. ('One who wets his bed'—Kichag.) Boil. Koroboi of Zanzibar, Bluggoe or Moko of the West Indies, &c. Overwhelmingly the commonest variety on the drier foothills of Kilimanjaro near Moshi. Ikonosi is the Kimachame version of the name.
Mkono wa tembo. ('Elephant's hand (i.e. trunk)'—Kisw.) Boil. Known under this name also at Amani and Zanzibar. Probably Gonja mamba of Western Uganda. Horse plantain of the West Indies.
Mnyenyeli. (Kichag.) Boil, bake, beer, dry, rarely raw. A common and important variety. Ilalyi or Njombo in the Kimachame dialect.
Mririwo. (Kichag.) Bake, beer. Uchochoa in Kimachame dialect.
Msekaseka. (Kichag.) Raw, boil, or beer. Mamweri in Kimachame dialect.
Msusu. ('A kind of tree' or 'tail feathers of a bird'—Kisw.) Boil, fry, or bake. A plantain type like Mkono wa tembo but with more and smaller fingers. Msinyore of Zanzibar, called Mbo in Kichagga and Mbwe in Kimachame.
Ndishi. ('Short'—Kichag.) Boil, beer. Ifwanaiya or Nduuya in Kimachame dialect.
Nduuya. (Kimach.) Ndishi.
Ngumadu. (Kimach.) Nyenyeli.
Njombo. (Kimach.) Mnyenyeli.

Nlelembo. (Kimach.) Nyenyeli.
Nshonowa. (Kimach.) Mchare.
Nyenyeli. (Kichag.) Raw, boil, roast. Nlelembo or Ngumadu in Kimachame dialect.
Uchochoa. (Kimach.) Mririwo.

Alien varieties

Kikanda. (A small, narrow, tapering matting bag—Kisw.) Raw, boil, beer. The Red and Green Red bananas. Also called Ndizi Uganda, Mgomba wa Uganda and, in Kimachame, Iruu lya Uganda.
Kimalindi. (A place-name—Kisw.) Cavendish, Kinguruwe, &c.
Kinguruwe. ('Little pig'—Kisw.) Raw, boil, beer. Cavendish, Canary, &c. Also as Kimalindi at Moshi and perhaps as Kiseri at Lyamungu, though this name also applies to a different variety akin to Makifui.
Kipukusa. ('Early dropping (fruit)'—Kisw.) Raw, beer. Probably Silk of the West Indies. Also called Kipungusa.
Kipungusa. See Kipukusa.
Kisukari. ('The sweet thing'—Kisw.) Raw, beer. Guindy of the West Indies. Ngusu in Kimachame is used for scarred fruit of this variety.
Mgomba wa Uganda. Raw, boil, beer. Red and Green Red bananas also called Ndizi Uganda, Kikanda, and in Kimachame, Iruu lya Uganda.
Ndizi Uganda. ('Uganda banana'—Kisw.) Raw, boil, beer. Red and Green Red bananas also called Kikanda and Mgomba wa Uganda and, in Kimachame, Iruu lya Uganda.
Ngusu. A Kimachame name for Kisukari with scarred fruits.
Unnamed. At Moshi in a garden. Mysore or Fillbasket of the West Indies, Kikonde of Zanzibar.

TANGANYIKA

AMANI

Native varieties (Kis. = Kisambaa; Kib. = Kibondei; Kisw. = Kiswahili).

Buo. (Name of a small fly (presumably Drosophilid) which settles on the overripe fruit in large numbers—Kis.) Boil or raw. Hills.
Dole. ('To take'—Kib. A single banana fruit—Kisw.) Raw or boil. Plains.
Kipanje. (Anything that ripens quickly—Kis., Kib.) Boil or roast, occasionally raw. A plantain type, probably Mzuzu of Zanzibar. Plains.
Kipukuru. (Quickly ripening and falling—Kib., Kis.) Raw or boil. Hills.
Kitombo. ('Breast' or 'udder'—Kib.) Raw. Hills. Ntindili is another name.
Libwi. ('Very smooth'—Kib., Kis.) Raw. Plains. Anthers abortive, shorter than the free tepal.
Lua lua. ('Orange-coloured flowers'—Kis.) Raw, boil, and favoured for flour-making. Mhalihali of Zanzibar. Plains.
Mboko. (?—Kib.) Raw and favoured for flour-making. A common and popular variety. Hills.
Mkono wa tembo. ('Elephant's trunk' (lit. 'hand')—Kisw.) Boil or sun-dried and cooked whole. Horse plantain, &c., as the Zanzibar plant of this name. Plains.
Mlema. ('Victor' or 'winner'—Kis.) Raw or boil. The male bracts are yellow with a tinge of purple at the distal margins. Hills and plains. Close to Pazi and perhaps really the same.
Muhoye. ('One that bends'—Kis.) Boil, rarely roast; or sun-dried and cooked whole. Plains. Plantain type, probably the French plantain of the West Indies, and Kichaange of Zanzibar. See also Ndizi ya Kiume.
Ndizi ya kiume. ('Like a penis'—Kisw.) Apparently a 'generic' name for plantains, including Muhoye, Kipanje, and Mkono wa tembo.

Nkokoma. ('Slope down'—Kis.) Raw or boil. Zahala.

Ntindili. ('Watery when boiled'—Kis.) Raw. Kitombo.

Pazi. ('Sick' or 'ailing'—Kis.) Boil, raw. Hills and plains. The male bracts are yellow with a tinge of purple at the distal margins. Close to or even identical with Mlema.

Pigiti. ('Very hard'—Kis.) Boil or raw. Hills. This is not the same as the alien Pigiti ya Moshi but resembles Tondwe rather closely.

Tondwe. (?—Kis.) Raw or boil. Hills.

Zahala. (?—Kis.) Boil. Hills. A curious variety with 1–2 hands, 2–10 fruits, numerous persistent floral relicts on the male rachis, and a very slender male bud with about 2 flowers per bract. Reminiscent of the Ugandan Nambi but probably not the same. Nkokoma is another name.

Alien varieties

Bokoboko. ('Soft', 'smooth'—Kisw.) Raw or boil. Bluggoe or Moko of the West Indies, Bokoboko or Koroboi of Zanzibar, Mkojosi of Moshi. However, the name is also used for Nyeupe ya Kizungu and Nyekundu ya Kizungu. It is perhaps surprising that this variety is not more grown on the plains below Amani in view of its abundance in apparently similar situations at Moshi and in Zanzibar.

Kibungala. ('Thick'—Kisw.) Raw. Probably Silk of the West Indies.

Kipukusa cha Java. ('Early dropping (fruit) from Java'—Kisw.) Raw, mostly sold in the markets. Probably Guindy of the West Indies.

Kisukari. ('The sweet thing'—Kisw.) Raw, mainly sold in the markets. As the Zanzibar plant of this name, with its characteristic bud.

Kisukari cha Kamba. ('Sweet thing for fibre'—Kisw.) Raw (rarely boiled), mainly sold in the markets. Sucrier of the West Indies, easily known by its non-waxy pseudostem.

Malindi. (Place-name—Kisw.) Raw, also boiled. Chinese, Cavendish, &c., and Kiguruwe of Moshi and Zanzibar.

Nyekundu ya Kizungu. ('Red of the European'—Kisw.) Raw, mainly sold in the markets. Red banana. Also called Bokoboko.

Nyeupe ya Kizungu. ('White of the European'—Kisw.) Raw, mainly sold in the markets. The green mutant of the Red banana. Also called Bokoboko.

Pigiti ya Moshi. ('Very hard, from Moshi'—Kisw.) Boil, raw. This is not the native Pigiti but probably only a similar variety believed to come from Moshi.

ZANZIBAR

(Kisw. = Kiswahili.)

Bokoboko. ('Soft, smooth'—Kisw.) A 'generic' name in Pemba for the Koroboi varieties [1].

Buki. ('Madagascar'—Kisw.) A name for Mzungu mweupe in Pemba.

Bungala. ('Bengal'—Kisw.) A name for Mzungu mwekundu in Pemba.

China. (Allegedly brought to Zanzibar by a Chinese.) Raw. Sucrier of the West Indies.

Kichaange. (? (Meaning lost)—Kisw.) Boil. The French Plantain of the West Indies.

Kiguruwe. ('Little pig'—Kisw.) Raw, a variety encouraged by the Department of Agriculture. Dwarf Chinese, Cavendish, &c.

Kijakazi. ('Small or child-slave'—Kisw.) Boil. Not a favoured variety.

Kikonde. ('Little field'—Kisw.) Raw, but unpopular. Mysore or Fillbasket of the West Indies. Plants at Kizimbani showed mild mosaic symptoms such as are frequent on the variety in Trinidad.

Kikonde (2). ('Little field'—Kisw.) Boil, a rare variety, not favoured. In the collection at Kizimbani as Kikonde (Dunga). Reminiscent of some Ugandan boiling varieties with short, fat fingers.

Kipukusa. ('Shaken from the tree'—Kisw.) Raw. Silk of the West Indies [1].

Kisukari. ('The sugary thing'—Kisw.) Raw. The male bud is broad and widely imbricate at the tip, giving the impression that 'the bracts are too small for the bud'.

Koroboi Chuku. (K.—'Muzzle-loading gun' (?) Ch.—'cupping-horn' (i.e. for blood-letting)—Kisw.) Boil. A most important variety in dry eastern Zanzibar on coral limestone. Bluggoe or Moko of the West Indies, Mkojosi of Moshi, &c. Also called Punda Tovu and Muscat nyeusi [1].

Koroboi maskati. (K.—'Muzzle-loading gun (?) of Muskat'—Kisw.) Boil. Like Koroboi Chuku but the fruits waxy. A most important variety in dry eastern Zanzibar on coral limestone. Silver Bluggoe or Silver Moko of the West Indies. Also called Muskat nyeupe and Punda Jivu [1].

Koroboi miraba. (K.—'Muzzle-loading gun' (?) M.—'lines, ridges or rows'—Kisw.) Boil. Like Koroboi chuku but bottle-neck at apex of fruit less pronounced. Also called Punda nyeupe [1].

Mchinja damu. ('Slaughter bloodily'—Kisw.) Boil, a favoured variety. A plantain type with long angular fingers, persistent bracts, and a malformed contorted male bud.

Mficha chana. ('Hide bunch'—Kisw.) Boil. Not seen. Said to retain the basal part of the bunch within the pseudostem. Perhaps Makifui of Moshi, which has this same habit.

Mhalihali. ('To strive after the unattainable'—but some other translations are possible—Kisw.—perhaps a reference to the height of the plant.) Boil. A tall plant with a large bunch and persistent bracts and flowers on the male rachis and a yellow male bud. Lua Lua of Amani.

Mjenga. ('Builder'—Kisw.) Boil. The bunch is small and horizontal, reminiscent of some forms of the wild *M. acuminata*. Mlali kifupa of Pemba.

Mjenga maua. (Mj.—'Builder', Ma.—'flowers'—Kisw.) Boil. The stamens of the male flowers are reduced to five short distorted relicts concealed within the free tepal. Mlali maua in Pemba.

Mkono wa tembo. ('Elephant's trunk' (lit. 'hand')—Kisw.) Boil, a favoured variety. Horse plantain of the West Indies, Mkono wa tembo of Amani and Moshi.

Mlali kifupa. A name in Pemba for Mjenga.

Mlali maua. A name in Pemba for Mjenga maua.

Mporomoka. ('Falling down'—Kisw.) Boil. A plantain type with numerous hands (up to 25), the fingers of the upper hands much larger than those of the lower hands. Very like Nkonjwa of Bukoba.

Msinyore. ('Do not drip' (polite imperative)—Kisw.) Boil, a favoured variety. Like the horse plantain (Mkono wa tembo) but with 5–6 hands of more numerous and smaller fingers.

Mtwike (or *Ntwike*). ('That you may lift a load and place on the head or shoulders'—Kisw. (polite imperative).) Raw. A variety encouraged by the Department of Agriculture. A semi-tall Cavendish type with deciduous bracts like, for example, the Congo banana or Giant Fig of Trinidad.

Muskat nyeupe. ('White Muscat'—Kisw.) A name for Koroboi maskati (Williams [1] gives Muscat jeupe).

Muskat nyeusi. ('Black Muscat'—Kisw.) A name for Koroboi Chuku [1].

Mzigo. ('Load'—Kisw.) A name in Pemba for Paji.

Mzomanga. A name in Pemba for Mchinja damu.

Mzungu mwekundu. ('Red European'—Kisw.) Raw. The Red banana. Bungala in Pemba.

Mzungu mweupe. ('White European'—Kisw.) Raw. The Green Red banana. Buki in Pemba.

Mzuzu. ('Stupid fellow'—Kisw.) Boil. A plantain type near Mchinja damu but with the male bud not contorted, imbricate at the tip.

Paji. ('Forehead'—Kisw.) Boil, but unpopular since said to 'taste of vinegar'. Mzigo in Pemba.

Paka. ('Cat'—Kisw.) Boil. A diploid variety with a neat pendulous bunch, yellow male bracts, and fair resistance to *Cercospora.* It has been imported to the I.C.T.A. for use in banana-breeding.

Pukute. ('Falling or shattering when shaken'—Kisw.) Boil, not a favoured variety. Fruit ripens green and can be eaten raw, when it has a distinctly acid flavour.

Punda. ('Donkey'—Kisw.) A 'generic' name for the Koroboi varieties in Pemba [1].

Punda jivu. ('Ash-coloured donkey'—Kisw.) A name for Koroboi maskati [1].

Punda mweupe. ('White donkey'—Kisw.) A name for Koroboi miraba (Williams [1] gives Punda jeupe).

Punda tovu. A name for Koroboi Chuku [1].

Sikuzani. ('I did not think so'—Kisw.) Raw or boiled but not favoured. Perhaps a diploid. The bunch is less shapely than that of Paka and sometimes the fruits contain a few seeds, usually abortive.

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INCIDENCE OF OESTRUS IN EWES

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THAT exteroceptive factors are important in determining the seasonal incidence of reproductive activity of many higher animals now seems well established. To date, most of the attention in this field has been devoted to the effect of light on mammals and birds [1, 2, 3, 4].

Underwood *et al.* [5] in Western Australia have observed that, within any flock of ewes under normal management, the incidence of oestrus and lambing is far from random. Following the introduction of rams into the breeding flocks, they noted a period of 16 days when relatively few ewes exhibited oestrus, followed by a period of intense sexual activity until the 24th day, the peak occurring between the 18th and 22nd day.

Following publication of the above observations, which were based on an examination of past oestrus and lambing records, experimental trials were commenced at Roseworthy College, South Australia. In 1946 and 1947 the merino flock (400 ewes) of South Australian (Bungaree) strain was divided into two equal groups. One group ('teased') was run with vasectomized rams for 16 days and then joined with fertile 'raddled' rams. The control ewes were not 'teased' and were joined with fertile raddled rams on the same day as was the 'teased' group. Fertile mating commenced in the second week of November in each year. In 1946 ewes exhibiting oestrus were recorded daily from the date of joining the fertile rams; in 1947 the daily incidence of oestrus was also recorded in the 'teased' group during the teasing period. The daily incidence of first occurrence of oestrus for the 28 days after fertile mating commenced is shown in Figure 1, in which the 1946 and 1947 results are combined. Chi-square examination of the results shows them to be significantly different during the first and third seven-day periods ($P < 0.001$).

Daily recording of oestrus was not continued during the 1948 and 1949 matings, but in these years all ewes were 'teased' for 16 days prior to introducing the fertile rams. The subsequent lambing results have been combined for the two years and are presented in Figure 2. Further observations on 450 merino ewes during mating in November–December 1950 gave the same results.

These observations fully confirm the 'log and peak' incidence of oestrus recorded by Underwood [5]. Parenthetically it may be noted that, when mated in November–December, the incidence of lambing in Border Leicester–Merino half-bred ewes at Roseworthy follows the same course as that observed in the Merino. Also, unpublished observations by one of us (D. S. T.) on a smaller number of Merino ewes mated later in the breeding season (March) failed to show other than a random distribution. It appears, therefore, that the incidence of oestrus recorded

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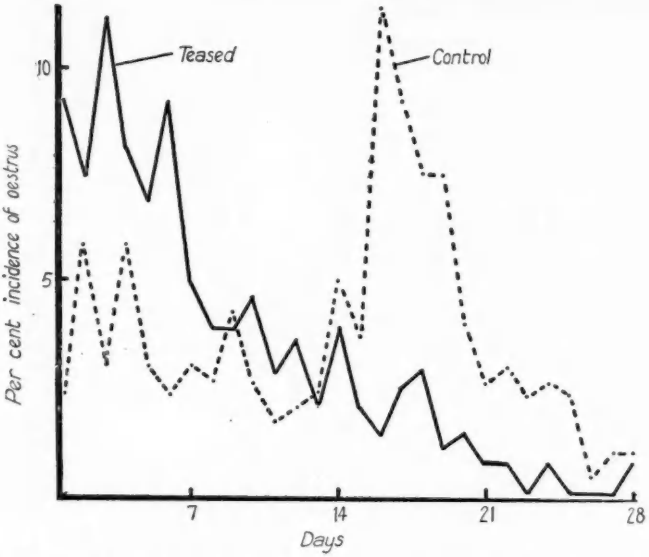

FIG. 1. Daily incidence of first occurrence of oestrus for the 28 days after fertile mating. Roseworthy, 1946, 1947

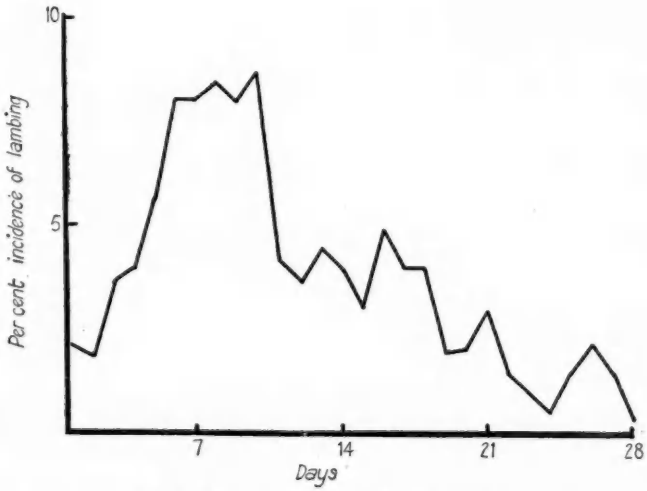

FIG. 2. Lambing results. Roseworthy, 1948, 1949

by Underwood [5], and confirmed here, may only occur following the sudden joining of rams when ewes are approaching the threshold in the transition from the non-breeding to the breeding season.

Other observations suggest that there may not be any marked stimulating effect of the ram in some breeds. Examination of the lambing records at Roseworthy of the Southdown flock (50 ewes) over a period of eight years reveals that in only one year was there any suggestion of a peak incidence of reproductive activity 16–22 days after joining the rams. Also, observations on the incidence of oestrus in a flock of Corriedales (100 ewes) for 2 years failed to reveal other than a random distribution of oestrus. Normally these breeds have a more restricted breeding season than the Merino or its crosses, and, at Roseworthy, neither breed exhibits activity before February. Further, observations by one of us (P. G. S.) on a limited number (12) of Romney Marsh at the School of Agriculture, Cambridge, have failed to show other than random distribution.

The introduction of the ram, as an exteroceptive factor stimulating reproductive activity, would thus appear to be most marked in those breeds in which the breeding season commences during periods of increasing daylight hours (extended breeding season), and to be absent, or very limited, in those breeds in which activity commences during the period of decreasing daylight hours (limited breeding season).

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RAINDROP ENERGY AND SOIL EROSION

WALTER D. ELLISON[1]

WITH PLATES 2, 3

SOIL erosion is a work process. Gullies, sheet-erosion scars, and other forms of erosional damages are products of this work. For more than 5,000 years men have striven to develop an art and science for the control of soil erosion, and during this time the primary attack has been directed at the control of run-off, with almost complete neglect of erosional damages that are caused by falling raindrops. Yet the falling raindrops, acting on the smooth surfaces of open fields, usually embrace several hundred to several thousand times more kinetic energy than does the run-off.

This energy of falling raindrops may be emphasized by comparing it with that of the average farm tractor. For this comparison a rainfall of 3 in. per hour, with drops falling at 30 ft. per sec., is assumed. It is further assumed that the drops penetrate the water and soil to a depth of $\frac{1}{4}$ in. before attaining zero velocity. Heat losses are not considered. Under these conditions 288 horse-power is developed by the raindrops that fall on one acre. This is equivalent to about 29 average farm tractors working on each acre of land for the period of rainfall. It represents enough energy to plough the land about 29 times during the one hour of rainfall. In violent rains that are accompanied by high winds, this great energy of the falling drops may be equal to ploughing the land once every minute of storm.

The blasts of raindrops beating on bare ground erode and damage the soils by breaking down their crumbs and splashing these broken parts (Plate 2, figs. 1, 2). This is the splash-erosion process. It is not visible to the unaided eye, and this fact has contributed greatly to our failure to recognize and appraise it. So long as the process remained unrecognized, many splash-erosion damages were entirely overlooked whilst others were charged to the actions of run-off or to other causes.

Splashes caused by water-drops falling into dishes of water and milk were first photographed by Worthington [1]. He was not concerned with damage to soils but with the behaviour of drops as they penetrated a liquid. Even before his photographs were published, some investigators had studied sizes and fall-velocities of raindrops and waterdrops. Among these were Lenard [2] and Bentley [3], but it was not until Laws's experiments [4, 5] that some effects of raindrop energy on soil erosion seem to have been measured. Even Laws's measurements were limited to some indirect effects; he examined only the run-off from experimental plots and did not study the soil splash. His examinations revealed that each increase in raindrop impacts caused an increase in the soil carried by the run-off.

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Recognizing that run-off from bare plots carried more soil than that from plots covered with a straw mulch, Borst and Woodburn [6] experimented to determine if the mulch produced these effects through dissipating raindrop impacts, or through impeding the surface-flow. After a period of experimentation, they concluded that impact was the important factor.

The writer's investigations [7, 8] into raindrop actions established splash erosion as an important process bearing on soil and water conservation, and led to the development of methods and techniques for measuring some of the most important factors involved. This work was begun about 1936 following some field observations on surface-sealing and pedestal formations. Some of the more formal of the exploratory experiments were carried out as a summer project by Dale Jenkins, a student at Ohio State University. Results of these explorations were not published, but they provided valuable background material for designing the experiments reported in references [7] and [8]. Following publication of these two references, a new definition was developed that described the erosion (work) process as one in which erosive agents detach and transport soil materials. Thus, two independent actions were recognized: (1) soil particles of transportable sizes are detached (torn loose) from their moorings in the surface of a soil mass; and (2) these detached particles are transported as splashes.

Developing New Techniques

The above definition disclosed a need of techniques for measuring the detachment and transportation processes separately [9]. The splash-board type of sampler [8], which had been used in early studies, could not be used in this way. Its catch depended not alone on the quantities of soils detached and set in motion, but also on how far the splashes travelled. As velocities of the falling raindrops were increased, the splash velocities also increased, and the effect of this was to increase greatly the surface-area contributing soil to the sampler. Under these conditions, the amount of soil caught by the splash-board underwent change with each change in either the detachment or the transportation caused by the splashes. A study of data from more than 50 experiments revealed the soil-catch by the splash-board to be proportional to drop-fall velocity $(V)^{4 \cdot 33}$.

To eliminate the variable of transportation from the splash measurements, and thereby make the sample reflect only differences in quantities of soil detached and set in motion, a small splash-dish was developed. This dish was made only 3·5 in. in diameter; so small that almost all of the soil detached and set in motion by raindrop impacts would splash out. To measure the soil-detaching capacity of falling raindrops, the dish was filled with round grains of standard sand of uniform size. Under these conditions, variations in rates and quantities of sand-splash were sensitive to variations in the impact of the falling drops. Thus the amount of sand splashed out of the dish was proportional to the splash-capacity of the falling drops. It required only a few tests to establish this as a practical technique for measuring the detach-

ing capacity of falling raindrops. Table 1 shows the different results in amount of sand-splash as indicated by the symbol D_3.

TABLE 1. *Experiments to determine Soil Detachability*

Expt.	*Soil*	*Duration min.*	*Vel. of drops ft./sec.*	D_1 *gm.*	D_3 *gm.*	D_2* $= D_1/D_3$	*Remarks*
1	Silt loam	9	23·9	10·5	42·4	0·25	Lintonia loam silt
		20		15·3	71·9	0·21	
		40		27·5	112·6	0·24	
1 A	Silt loam	8	23·9	9·2	39·8	0·23	Crosby loam silt
		19		16·6	70·9	0·23	
		40		23·7	115·7	0·29	
2	Sandy loam	8	23·9	27·4	41·6	0·66	Cultivated
		19		45·4	71·9	0·63	
		40		83·9	122·4	0·68	
2 A	Sandy loam	8	23·9	24·6	Same	0·59	Pasture
		19		43·4	as 2	0·60	
				77·4		0·63	
3	Hard lands	9	23·9	25·4	51·2	0·50	Poor range
		20		29·3	82·3	0·48	
		41		73·8	134·1	0·55	
3 A	Hard lands	9	23·9	27·3	Same	0·53	Excellent range
		20		42·4	as 3	0·51	
		41		71·0		0·53	

* D_1 and D_3 are measured and D_2 is computed; $D_2 = D_1/D_3$.

When samples of different soils were placed in splash-dishes and subjected to equal drop-impacts, the losses from the different samples varied widely. This variation was considered to be due to the relative detachability of the soils, which is inversely proportional to the resistance a soil offers to separation and movement of its particles. A soil of high detachability would have a large splash-loss from the dish, whilst one of low detachability would suffer only a small loss. It was found convenient to express soil detachability as a ratio equal to the splash-loss from the soil, divided by the splash-loss from the standard sand, where both dishes were exposed to equal raindrop impacts. Thus a soil that lost 40 gm. by splash, while the standard sand lost 80, would have a detachability of 0·50. This detachability factor was designated by the symbol D_2.

At this stage it was possible to write a detachment equation in which the amount of soil detached and set in motion would be proportional to the product of (1) the detachability of the soil, and (2) the detaching capacity of the drop impacts expressed in terms of grams of standard sand splashed from the dish. The equation is: $D_1 = D_2 \times D_3$, where, in splash-erosion work,

D_1 is the amount of soil detached (it is referred to as the detachment hazard and it is equal to the grams of soil splashed from a splash-dish).

D_2 is the soil's detachability (it is measured and expressed in terms of the grams of soil splashed from a splash-dish, divided by the grams of standard sand splashed from a like dish).

D_3 is the detaching capacity of the falling raindrops (it may be measured as grams of standard sand splashed from a splash-dish).

The above equation will apply so long as the soil is bare. But, if an energy dissipator such as a vegetal cover is introduced, the energy of falling rain is reduced before the drops contact the soil. This modification of the rain's detaching capacity is written into the detachment equation as follows: $D_1 = D_2 \times D_3/R$, where

R is the protective value of a vegetal cover (it is equal to the total detaching capacity of falling raindrops as they enter the vegetal canopy, divided by their detaching capacity as they contact the soil, or, mathematically, $R = (D_2 \times D_3)/D$).

The above equation reveals that the factors affecting the detachment hazard can be divided into three groups. These are: factors of the soil (D_2), factors of the raindrops (D_3), and factors of the protective cover (R). Experiments have shown that the net effects of important changes within any one of these three groups of factors may be accurately measured in terms of an increase or a decrease in the detachment hazard (D_1). They have also shown that erosional damages associated with any specific value of the detachment hazard may vary widely from one field condition to another.

The term erosional damages, as used in this discussion, implies any form of direct damage to lands and soils which may be caused by active erosion. Four common and very important forms of erosional damage, along with causes, are the following: (1) gullies carved principally by the scouring actions of run-off (gully erosion); (2) removal of sheets of surface soil, either by the splashing raindrops, or by the raindrops and surface-flow acting as a team (sheet erosion); (3) removal of the soil's fertility elements by the raindrops splashing them into suspension and the run-off floating them away (fertility erosion) [10, 11]; and (4) damage to the soil's structure by the blasting and beating actions of falling raindrops, by slaking, and by the intake of surface-water made turbid by the splashes (puddle erosion) [11, 12].

Very little has been done in relating variations in each of the D-factors to variations in each of the foregoing types of erosional damages. However, since publication of the papers listed in reference [9], which were followed by a related article [13], many measurements have been made of each of the D-factors, and many of the associated erosional damages have been observed.

Splash-Erosion Factors

The D_3 factor.—The standard sand used in this work is a round grained, smooth silica sand that passes a 60-mesh screen and is retained on a 70. A cotton wick feeds water into the sand and keeps it wet so that it will not blow away between rains. The sand must be oven-dried and weighed at the time the sample is prepared, and again after the rain.

As the sand in the dish is lowered by splashing out, interference by the side-walls of the dish causes the splash-rate to decrease. Bisal [14] designed a constant-level dish for determining the rate of this decrease, and developed a formula for correcting the results of measurements made with the old-style dish. His work represents an improvement in the techniques for measuring the D_3 factor.

Ekern [15] found the detaching capacity of the falling drops to be proportional to their momentum. Bisal suggested that some of his preliminary data showed a relationship of $V^{1.39}$. This relationship also fits data which the writer compiled from a small group of his early experiments.

Very little is known about the detaching capacities of natural rains. Osborn [16] reported that over a 10-month period at San Angelo, Texas, the maximum detaching capacity measured was 81 gm. of sand from the splash-dish, and this was for a rain of 1·50 in. If this splash in gm. is multiplied by 0·71, the product is the equivalent tons per acre; in this case $81 \times 0{\cdot}71$ equals 57·6 t. of standard sand-splash per acre.

In some unpublished experiments near Nashville, Tennessee, conducted by chemical engineers of Monsanto Chemical Company, on which the writer served as consultant, the measured detaching-capacity of a rainfall of 3·8 in. was found to be 169 t. per acre. On a soil having a detachability of 0·65, this rain produced soil-splash in a sampler equal to 105 t. per acre on bare soil.

The D_1 factor may be measured by using a soil instead of a sand in the splash-dish, and exposing it to rainfall. D_1 is then equal to the weight loss of soil, based on oven-dry conditions.

The D_2 factor.—After D_3 and D_1 have been measured the values of D_2 (equal to D_1/D_3) can be computed. Since they are not wholly independent of variations in drop-impact characteristics, a standard rain is needed in the basic experiments. The recommended standards are 2 in. in 20 min., with drops of approximately 5·5 mm. diameter, falling from a height of 14 ft. Additional tests may be required in those regions where the important erosive rains vary widely from these standards. For these additional tests, artificial rain, more nearly duplicating the natural rainfall of the region, may be used.

In a previous article [9] the writer showed an inexpensive apparatus for applying 'rain' to a soil sample in the laboratory. Several types of equipment to be installed on trucks were later designed and an improvement to one of these was later used by Osborn [17].

Owing to the difficulty of producing uniform rain over an area, it is important that a turn-table be employed and that care be taken to rotate all of the samples through a common path. The samples may be moved along the circumference of the circle at a speed of about 1 ft. per sec. (Pl. 3, fig. 2).

Since the detachability of a soil varies with its structural conditions, a standard structure had to be developed. This was done by oven-drying the soil and screening it through a sieve of 2 mm. openings. Under these conditions, the test results with each different soil were duplicated with considerable accuracy. However, wide differences were

found to exist between the various soils. This fact is illustrated by some of the writer's results [19] as shown in Table 1.

TABLE 2. *Organic Matter and Detachability of Silt Loams*

Expt.	*No. of samples exposed*	*Exposed to rain min.*	*Soil*	*Loss in gm.*		D_2 *computed*	*Organic content**
				D_1 *from soil*	D_3 *from sand*		
1	3	9	Crowly silt loam	10·5	42·4	0·25	Low
2	3	20		15·3	71·9	0·21	
3	3	40		27·5	112·6	0·24	
4	3	8	Crowly silt loam	25·9	36·9	0·70	Medium
5	3	19		39·4	75·1	0·52	
6	3	40		63·0	116·4	0·54	
7	3	8	Crosby silt loam	16·3	36·9	0·44	High
8	3	19		30·3	75·1	0·40	
9	3	40		51·0	116·4	0·44	

* The organic content of soils not measured and results in this column are based on observations only.

In the limited number of tests that have been made, the silts have averaged lowest in detachability, the clays intermediate, and the sands highest. The amounts and conditions of organic matter present are important factors affecting the detachability. The detachability of the silts was lowest when their organic matter was low. More work is required to explore and establish the relationships of organic matter and soil detachability to a point of practical use. Table 2 shows typical results from the limited amount of work carried on thus far.

It is important to determine the detachability of a soil in field condition (undisturbed natural structures) as well as to test it under the standard structural conditions produced by screening. Woodburn [18] and Osborn [16] both tested soil-cores taken from open fields without destroying their natural structures. As a general rule, much lower detachability prevails where the soil's natural structure has not been destroyed.

Soils containing stones so large as to make it impracticable to test them in small splash-dishes may be tested in the field with the splash-frame (Pl. 3, fig. 1). The usual dimensions of this frame are 12×18 in., and since all of the splash within it does not reach the sides of the plot to be collected in the sampling troughs, a relationship must be established between the splash-catch in this frame and the splash-loss from the dish. This relationship serves to compare detachment measurements made with each type of equipment.

A large number of exploratory tests, some of which were never published, have shown D_2 values to range from as low as about 0·07 to as high as about 1·40. The lower values were for compact soils of undisturbed, natural structure, whilst the higher values apply to thoroughly pulverized soils.

Broad generalizations must be avoided in making application of soil-detachment data. Equal detachment hazards on different field conditions often produce widely different results. Some different field conditions that will suffer widely different erosional damages due to soil-splash are: (1) steep slopes having a high detachment hazard suffer high rates of sheet erosion, but flat lands where detachment is high may suffer very little sheet-erosion damage; (2) soils that puddle badly, where there is high detachment, puddle and seal against the intake of air and water, but many flat-land sandy soils may puddle but slightly, and here the principal damage is fertility erosion.

The R factor.—The splash-frame (Pl. 3, fig. 1) is used for determining the protective value (R) of a vegetal cover. The procedure is to use the values of D_2 obtained in experiments using the small splash-dish, but a new value of D_3 must be obtained. This new value is obtained by filling the splash-frame with standard sand and exposing it to artificial rain. For this purpose, the intensity of impact must be equal to that used in the cover evaluation experiments. With this new value of D_3, and the value of D_2 from the splash-dish experiments, the value of D_1 (the splash-hazard) can be computed for a bare soil ($D_1 = D_2 \times D_3$). Where soils are partly covered by vegetation, the difference between this computed splash for bare soil, and the actual splash with partial cover, will reflect the protective value of the cover. This protection factor is the R value, and it is computed by the formula $R = D_2 \times D_3/D_1$.

Osborn's experimental measurements of the R factor are the most extensive ever made [16]. The writer's experiments were made under circumstances much less favourable than his, but the results compare favourably. The data in Table 3 show typical results obtained in a large number of such experiments.

TABLE 3. *The Protective Value of Vegetal Covers*

Expt. no.	*Soil detachability* D_2	×	*Raindrop detaching capacity* D_3 *gm.*	=	*Soil detached when ground is bare* D_1 *gm.*	*Soil detached with partial cover gm.*	*Forage and litter cover per acre lb.*	*Value of R*
1	0·72	×	500	=	360	98·2	637	3·7
2	0·50	×	500	=	250	3·68	2,300	68·0
3	0·60	×	500	=	300	1·94	4,270	155·0

Screenivas [20] compared the protective value of different types of vegetation. He determined that pound for pound the grasses and mulches that were composed of the finer straws provided the most effective protection for the soils. He expressed his results in terms of the percentage of the total soil-splash that the cover eliminated. Osborn used this same method of expressing the protective value of grass and mulch covers.

Erosional Damages

Soil erosion was once defined as a wearing away of the land. Although this is approximately correct, the definition stated in this way has proved

misleading. The fact that there could be wearing-away and building-up processes going on simultaneously at a single point seems to have been generally overlooked in most soil-erosion investigations. In some cases the eroded soils were redeposited near their original positions an instant later. This usually happened on flat surfaces where the splash-erosion process was active. The beating and splashing raindrops caused erosional damage to the soil's physical, biological, or chemical properties, but they did not cause important amounts of soil loss.

Acceptance of the wearing-away definition seems to have been responsible for the general practice of using the terms *soil erosion* and *soil loss* as synonyms. One very undesirable result of this viewpoint has been to measure the beneficial effects of conservation- and erosion-control practices in terms of their reducing soil loss. Such an approach does not admit the possibility of energy being expended in erosional work without producing soil loss from some previously defined area.

But soil loss is only one of several types of erosional damage. The nature of the other damages caused by erosion may vary according to the erosive agent causing them. The two principal agents active during rainstorms are the falling raindrops and the run-off. The raindrops that act uniformly over broad surfaces produce various sheet-erosion effects, whilst the run-off, which acts along narrow lines of flow, scours and carves rills and gullies. As a prerequisite to the design of effective erosion-control practices, each of the various damages must be identified with the actions causing them. One of the first types of damage produced by the falling rain is that of puddling the soil (puddle erosion).

Puddle erosion.—Puddle erosion [11, 12] represents one form of erosional damage not dependent on soil loss. The impact of raindrops that break up aggregates and compact a soil will increase soil density. This density is further increased by the infiltration and percolation of waters made muddy by the splash process. In a strictly technical sense, deposits from muddy waters percolating through a soil represent indirect rather than direct erosional damages. However, they account for but one part of the result referred to as puddle erosion.

Puddle-erosion damages occur on all types of soils, from coarse sands to fine clays, but they are generally most injurious on clay soils. The surfaces of many of the clays, and some of the silts, are so easily sealed and waterproofed by the splash of high-velocity raindrops that more than 90 per cent. of their infiltration-capacity may be destroyed during a few minutes of high-impact rain. Aggregate breakdown is a first step in most surface-sealing processes. Many aggregates classed as 'water-stable' by previously accepted standards were found to fail when subjected to raindrop impacts. This indicates a need for new testing standards in the aggregate analyses to be used in puddle-erosion studies.

Breakdown of these water-stable aggregates by raindrops was measured in the following experiment on Muskingum silt loam. Before raindrops were applied, aggregate tests showed that 53·5 per cent. of the surface soils passed the 0·105 mm. wet screen, but following the rain this percentage was found to have increased to 56·7. The aggregate breakdown was even greater than indicated by these percentage changes,

because of the soil carried in the run-off; 87·7 per cent. passed this wet screen, whereas of the original soil only 53·5 per cent. was of this fineness. Further study of the surface-materials, following the rain, revealed that 46 per cent. of the aggregates larger than 1·0 mm. had been destroyed by the rain.

It is common knowledge that the infiltration and percolation of muddy water will plug and seal a soil's pores. This plugging is first made apparent as a surface-seal, and the forming of this seal will vary with the amount of soil contained in the surface-water. Text-figure 1 is based on several experiments designed to show variations in the soil-content of surface-waters, caused by variations in raindrop impacts. Each increase in these impacts caused an increase in the soil-content of the run-off.

After it had been determined that the soil-content of surface-water was sensitive to the drop-fall velocities, some infiltration measurements were made under different drop velocities. A group of these experiments is shown in Table 4. It is recognized that only a part of this reduction in infiltration was caused by stirring soil materials into the surface-water. Another part must be ascribed to breaking of soil aggregates and to compacting the small broken fractions into a solid and impervious surface-layer.

TABLE 4. *Variations in Raindrop Velocities and Infiltration**

Expt. no.	*Drop vel. ft./sec.*	*Drop diam. mm.*	*Rainfall intensity*	*Infiltration-rate in. per hr.*		
				First 5 min. of rainfall	*First 15 min. of rainfall*	*First 30 min. of rainfall*
1	0	5·1	6·8	6·8	6·8	6·8
2	3·1	5·1	6·9	5·7	4·6	3·5
3	6·1	5·1	6·5	4·9	2·7	2·1
4	10·2	5·1	6·7	2·0	1·0	0·7
5	20·4	5·1	6·5	0·7	0·3	0

* Experiments and analysis by R. L. Burling and W. D. Ellison.

Other experiments have shown that reductions in infiltration caused by increasing the drop impacts vary from one soil to another. Both the state of aggregation and the clay-content of a soil were found to have an important effect. Each increase in the state of aggregation tended to increase the infiltration capacity of a soil and to curtail surface-sealing, whilst each increase in clay-content (from soil to soil) tended to decrease this capacity and to increase surface-sealing. Table 5 shows some typical results.

TABLE 5. *Some Effects of Aggregates and Clays on Infiltration*

Soil	*Aggregates larger than 0·105 mm.* %	*Clay-content of soil* %	*Infiltration, in. per hr., for a 25-min. period*
A	80	6	3·1
B	80	12	1·4
C	67	12	0·7
D	44	14	0·2

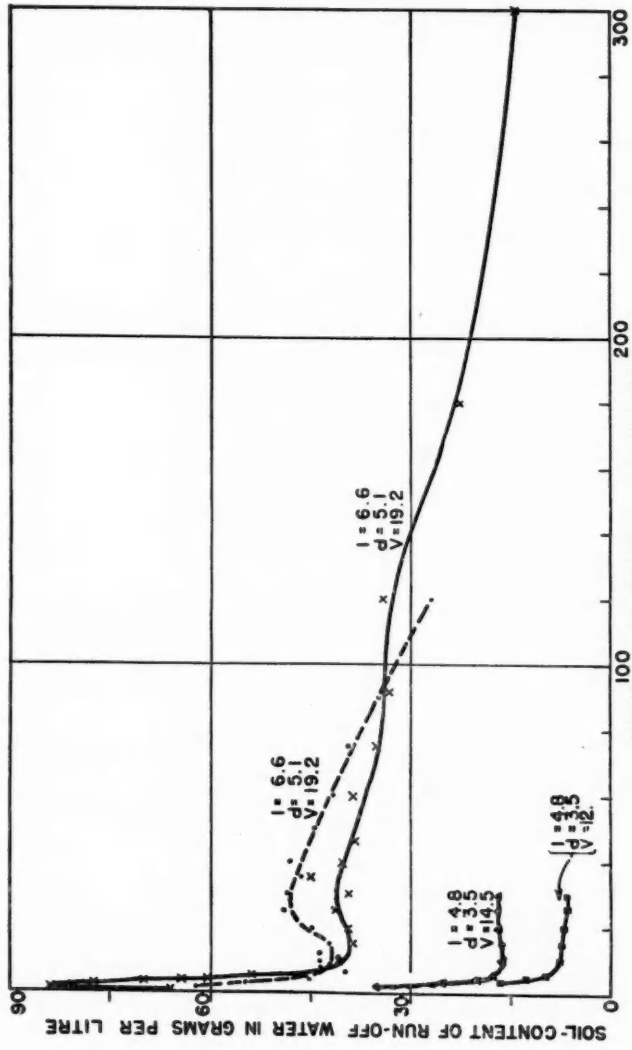

FIG. 1. Curves showing soil-content of run-off under different applications of 'rain', after various elapsed periods of artificial rainfall. The letter *I* indicates intensity of rainfall in inches depth per hour; the *d* indicates diameter of 'raindrops' in mm.; and *V* indicates the fall velocities of drops in ft. per sec. at point of impact.

In a series of experiments relating to spray irrigation, Peel, Beal, and Lesesne [21] found variations in the mechanical analysis of a soil to have pronounced effects on infiltration when the water was applied as artificial rain, using a Type-F Nozzle. Table 6 shows their results.

TABLE 6. *Mechanical Analysis and Infiltration under Raindrops*

	Mechanical analysis			*Infiltration, in. per hr. after 60 min. of rainfall*
Soil	*Sand* %	*Silt* %	*Clay* %	
1	98·6	0·4	1·0	3·50
2	96·1	1·4	2·5	3·50
3	92·9	3·0	4·1	1·15
4	89·9	5·3	4·8	0·75
5	86·8	7·5	5·7	0·61
6	80·8	11·0	6·9	0·60
7	78·3	12·2	9·5	0·24

These investigators also conducted an experiment to determine if a straw-mulch would improve infiltration most if left on the surface, or incorporated into the soil. They selected two plots on a soil having an infiltration capacity of 0·42 in. per hr. when bare. To one of these they applied 2 t. of straw and incorporated it into the soil. To the other they applied 2 t. of straw per acre as a surface-mulch. After 6 months they applied artificial rain and found the incorporated plot to have an infiltration capacity of only 0·49 in. per hr., whilst the mulch-covered plot had a capacity of 2·18 in. per hr. This led them to conclude that the greatest benefits of straw for improving infiltration lie in protecting the surface against raindrop impacts.

Puddle-erosion goes deeper than the surface. Many cultivated soils tend to develop impervious plough-soles, and in some instances deep seepage-ways seem to be slowly sealed off by turbid waters filtering through the underground materials. These turbid waters may enter the soil through temperature cracks, worm- and rodent-holes, and through other surface openings. Upon reaching the lower end of such a flow channel, the silt load may be filtered out; thus increasing soil density in deep sections of a profile. It is believed that deep sealing on many soils, following centuries of excessive 'bare-land farming', tends to retard the entrance of surface-waters into deep underground reservoirs. This development practically isolates many of these reservoirs from their principal source of replenishment, i.e. the rains. But even before this deep sealing becomes effective, most of the rainfall may be directed into the run-off channels by the surface-seals that form on bare soils during a single rain, and by the highly impervious plough-soles that form over many years of row-crop farming.

Fertility erosion is most effective on soils containing much sand: these give up their organic matter, their fines, and their chemical nutrients easily when they are stirred by splashing raindrops. The effects are much the same as washing a bucket of sandy soil in a washing-

machine, providing there is constant overflow to carry off the light materials as they are stirred into suspension by the agitator.

On open fields, raindrop splashes stir the fine and light materials into suspension, and the run-off carries them away without ever seeming to transport large amounts of soil materials. A conservation technician once commented that certain flat sandy lands did not need erosion-control because measurements of soil-loss had revealed less than 4 t. per acre per year. 'That', he commented, 'is below the tolerable maximum which we have set as our goal in erosion-control work.' One look at the washed-out sandy fields that were being literally destroyed by fertility-erosion lent weighty evidence to the fact that conservation objectives are often obscured; so obscured in this case that primary concern seemed to be with the continent's wearing away rather than with the physical, biological, and chemical conditions of the soil.

In some analyses of run-off from a sandy loam in New Jersey, Neal [22] found it to contain 4 times more organic matter, 1·5 times more phosphoric oxide, 1·4 more potassium, and 2·3 times more calcium than the field soil which the run-off washed.

When sandy soils lose their fertility elements through erosion they also lose their water-holding capacity to an extent that they may become very droughty. Attempts have been made at improving these damaged soils with additions of organic matter. However, without first bringing splash-erosion under control, losses of fertility elements and organic materials often make this a very wasteful procedure.

Sheet-erosion.—Although sheet-erosion which is caused by rainstorms may be produced in at least three different ways, most of it is due to the splashing raindrops and flowing surface-water acting as a team. In this team-work, the splashing raindrops detach soil particles and set them in motion. The run-off, made turbulent by the splashes, helps to transport these detached particles down slope. The popular concept of a sheet of flowing surface-water carving away a thin layer of surface-soil from the full width of a slope has been found incorrect. It is true that very thin films of water moving down slope may assist in transporting eroded soils. But this water that moves in films does not acquire erosive velocities. Its transporting energy is in the form of turbulence imparted by splashing raindrops. Scour-erosion does not occur until flow along very narrow lines of action acquires sufficient velocity to carve rills and gullies. This kind of erosion never scours sheets of soil from broad surfaces.

Some effects of raindrop impacts on the soil-content of run-off are illustrated by the experimental results shown in Text-fig. 2. In these experiments the raindrops and surface-flow were applied alternately and in combination to small run-off plots, and the soil-content of the run-off tested under each condition. The samples for testing were collected as the water flowed off the lower ends of the plots. The results showed that immediately following each change in the method of applying water, the frontal wave of the run-off carried more soil than the run-off that followed. It is believed this increase in the soil carried may be caused in part by the greater turbulent energy of the frontal wave,

and in part by the sudden change in energy applications, which seemed to necessitate some shifting of soil particles on the surface in order to re-establish a condition of stability.

Plots for the experiment summarized in Text-fig. 2 were 20 ft. long, 6 ft. wide, and of 10 per cent. slope. The raindrops were applied with Type-F nozzles. These nozzles delivered drops with only a small percentage of the impact of a violent thunder-shower. Even these light impact drops did not reach the soil unchecked. A canopy of stubble

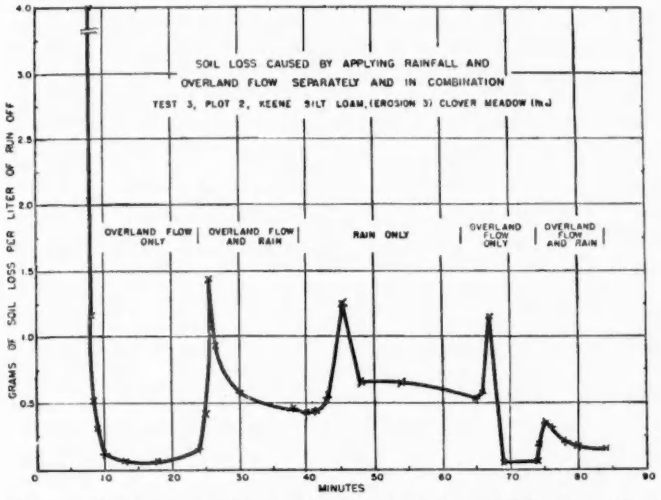
SOIL LOSS CAUSED BY APPLYING RAINFALL AND
OVERLAND FLOW SEPARATELY AND IN COMBINATION
TEST 3, PLOT 2, KEENE SILT LOAM, (EROSION 3) CLOVER MEADOW (In.)
GRAMS OF SOIL LOSS PER LITER OF RUN OFF
OVERLAND FLOW ONLY
OVERLAND FLOW AND RAIN
RAIN ONLY
OVERLAND FLOW ONLY
OVERLAND FLOW AND RAIN
MINUTES

FIG. 2. Variation of soil-loss with time, applying rainfall and overland flow separately and in combination. Clover meadow.

and young clover partly covered the ground; but some bare plots were used in later experiments, and although the losses were about 40 times greater, the soil-loss curves were of the same general shapes as in Fig. 2.

A second way in which sheet-erosion is produced is by the splashes of falling raindrops acting alone without any run-off whatever. These splashes 'beat' the soils down the slopes in much the same way that they beat down and level a small sand pile in an open yard. Ekern's [15] findings showed that most of the splashed soils were thrown in down-slope directions. This important finding explains one reason why splashing will cause the surface-soils to creep toward the base of a hill. Another cause for this creep is that those splashes 'kicked' in down-slope directions travel greater distances than those 'kicked' up slope.

Soil transportation may be expressed as a product of pounds of soil and feet of distance through which these pounds are moved. This product is one of pound-feet, and the downhill creep of splashed soils is equal to the pound-feet of downhill splash, minus the pound-feet of uphill splash. On a 17 per cent. slope (according to Ekern) 2 lb. of soil splashed in down-slope directions for every 1 lb. of uphill splash. And

further, according to unmeasured observations by the writer, the splashes moving down such a slope would travel about 3 times as far as those moving up grade; accordingly, there would be (2 lb. × 3 ft. =) 6 lb.-ft. of down-slope transportation for every (1 lb. × 1 ft. =) 1 lb.-ft. of up-slope transportation. Some of the writer's exploratory measurements [7] of up-and-down slope transportation of soil by the raindrop splashes were in line with this estimate. They showed 3 times greater transportation downhill than up, on a 10 per cent. slope.

A third way that sheet-erosion scars are produced is through the surface-flow scouring out rills, and then filling in these rills during tillage operations. This type of scar will usually appear lower on the hill-sides, down where considerable quantities of water flow. But the sheet-erosion that is produced either by the splashing raindrops acting alone, or by raindrops and surface-flow acting as a team, will appear first at the very crests of the slopes-up, where only very small amounts of run-off concentrate.

Intensity of splash-erosion is dependent on differences in the velocities of falling raindrops. In natural rains they vary greatly. One factor that has considerable effect on them is drop size [4]. A second is velocity of the wind. In some gentle rains where the drops are small and there is no wind, they may strike a soil at velocities below 25 ft. per sec. But during violent thunder-showers accompanied by high winds, large raindrops often are driven into the soil at velocities ranging upwards of 40 ft. per sec. These high-velocity drops produce many times more erosion than do the gently falling rains. Some of the effects of changes in drop velocity and size were brought out in a study [7] previously mentioned; a study in which the splashed soils were caught on a splash-board. The results of several representative experiments taken from this work are given in Table 7.

TABLE 7. *Effects of Raindrop Velocities and Sizes on Soil-Splash*

Expt.	*Drop diameter mm.*	*Rainfall intensity in./hr.*	*Drop-fall velocity ft./sec.*	*Splash grams of soil*
1	3·5	4·8	18·0	227
2	,,	,,	14·5	68·0
3	,,	,,	12·0	15·3
4	5·1	,,	19·2	526
5	,,	,,	15·0	209
6	,,	,,	12·0	28·0

Results of more than 50 experiments, of which those in the Table are a part, were fitted with the relationship

$$\textit{Splash-catch} = K\, V^{0.33}\, d^{1.07}\, I^{0.63}.$$

In this relationship the splash-catch was measured in grams; K is a constant which is probably affected most by the area of the splash-board exposed to splashing soil; V is the velocity of falling drops

measured in feet per second; d is the diameter of the raindrops (assuming them to be spherical); and I is the intensity of rainfall, measured in inches-depth of water that falls in 1 hr.

It was stated previously that owing to the experimental techniques employed, the amounts of soil caught with the splash-board are dependent on both the detachment and transportation processes. Later experiments, particularly experiments by Frederick Bisal, indicate that the detaching capacity of falling raindrops varies approximately as $V^{1.4}$. Since the soil-catch for the experiments represented in Table 7 varied as $V^{4.33}$, it may be assumed that most of this difference between the detachment and total catch of splashed soil is caused by a change in the surface-area contributing splash to the sampler. Each increase in the fall-velocity of the drops tends to cause an increase in velocities of the flying splashes. These increases in splash-velocities would, in turn, cause an increase in the surface-area which contributes soil to the splash-boards.

Gully erosion.—The gully is a form of erosional damage principally caused by the scouring actions of run-off. The gully is often more injurious to the terrain than to the soil. The major contributions of raindrop impacts to gully erosion are indirect, one of which takes the form of increased run-off associated with the splash-erosion process. Another is the increase in the abrasive properties of run-off, caused by soil fractions being stirred into the surface-water by the splashing raindrops. To some, it may seem a rash overstatement to claim that most of the flash run-off along with most of erosional damages that impair fields have their beginnings in the splash of raindrops; yet, many splash-erosion experiments show that they do.

The splash-erosion process also makes a direct contribution to gully erosion. It does this through splashing soils down the side-slopes of the gullies. In certain highly detachable soils this down-slope splash represents a very significant contribution to gully formations. There are instances where gullies have been extended in both width and length to an extent of 'eating up' a small field. No small part of the erosion causing these extensions should be charged to the actions of raindrops in beating down the side-walls, and to the actions of run-off in carrying this splashed soil away through the gully channels.

Other damages.—There are many indirect damages associated with the splash-erosion process. Most of the colloidal matter, which in stream-flow is injurious to fish life, and which makes up a large part of the deposit in many large reservoirs, is released from field soils when the soil is splashed. Another important matter is the effect of splash-erosion on grain and seed left on the surface as feed for wild life. Splash-erosion may either bury or remove much of this feed if the land is bare. The splash-process also may release small and light seed and fertilizers from seed-beds and stir them into suspension where they are transported down slope.

Another important form of splash-erosion damage is caused by the splashed soils lodging on vegetation. Most of us have tasted soil particles in spinach, turnip greens, and other garden vegetables. A quart of

unusually dirty strawberries recently purchased on the Washington market was found to contain 3·14 gm. of soil that had been splashed on to them by falling raindrops.

Soil splash also may damage feed and forage. Measurements of soil splashed on to forage in badly overgrazed pastures in Tennessee revealed that some of these grasses, after certain rains, may contain as much as 700 lb. of soil per ton of oven-dry vegetation. Amounts ranging from 10 to 100 lb. were not unusual in badly overgrazed pastures. The gritty effects of this soil on an animal's teeth could be bad. But these highly phosphatic areas, which are subject to high rates of splash-erosion, contain large amounts of fluorine chemically combined with the phosphorus as a fluorapatite. Many cattle grazing on these areas have ingested sufficient fluorine to show definite symptoms of fluorosis. Tobacco is another crop which may be severely damaged by splash-erosion deposits on the lower leaves.

Summary and Conclusions

Rain is more than water. It is water plus energy. This energy is enormous. It can be completely controlled with vegetal cover, but if not so controlled it will cause many forms of erosional damage. Since the splash-erosion process has not been generally recognized, some of its injurious effects have been charged to the actions of flowing surface-water, whilst others have been entirely overlooked.

Splash-erosion techniques have been developed to a point where they provide practical methods for evaluating storms and soils, for determining splash-hazards, and for evaluating beneficial effects of crops, meadows, and other protective covers. Splash techniques and procedures have now been advanced to a point where the necessary data can be obtained for matching each land area with a vegetal cover that will ensure the protection needed effectively to conserve its soil and water.

Erosional damages caused by raindrops will be found to differ with changes in soils and slopes. Puddle-erosion represents an important damage on flat, clayey lands; on flat sandy lands fertility-erosion may be very destructive, and on steep lands sheet-erosion is the outstanding form of damage. Since splash-erosion causes an increase in run-off by puddling and sealing soil, and since it may charge this run-off with abrasive soil fractions, many gullies are carved where there would be no gullies at all if splash-erosion were effectively controlled.

The many damages caused by splashed soils lodging on vegetation have hardly been recognized in the past, and very little has been done to control them. One very important line of exploration still before us concerns these indirect erosional damages caused by the splashing of soils.

Splash-erosion control is a MUST in soil- and water-conservation. Until we develop effective practices to control splash-erosion, and make them a basic part of the job, our techniques for protecting a soil are but little advanced over those of 5,000 years and more ago. History has shown that the usual contouring techniques that do not control the splash-erosion process have never been fully effective in conserving

FIG. 1. Splashing wet soil thrown up by a water-drop striking a wet soil

FIG. 2. Splashing soil and water thrown up by a water-drop striking soil that is covered with a thin film of water

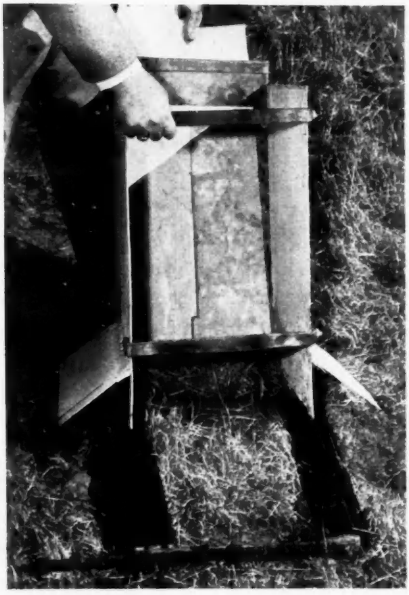

FIG. 1. The splash-frame used for measuring the protective value of soil cover; also for testing the detachability of a soil in field condition

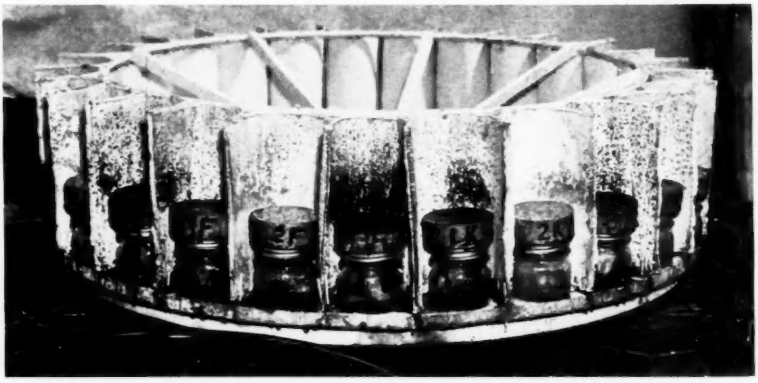

FIG. 2. The turn-table for testing the detachability of soils

soils over the long pull, especially in regions of violent rainstorms. The evidence also shows that it is folly to attempt the control of flood run-off with field-conservation practices which do not first of all control the blast of the raindrop and thereby preserve the water-intake capacity of the lands.

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THREE EXPERIMENTS IN WITCHWEED CONTROL

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THE common Witchweed of the Sudan is *Striga hermonthica* Benth., and is a widespread parasite of dura (*Sorghum* spp.), dukhn (*Pennisetum typhoides* (Burm. f.) Stapf. & Hubb.), and other grain crops. Only locally, however, does it become the great menace to cultivation which it constitutes in parts of South and East Africa. Losses are nevertheless caused by it annually and, in efforts to reduce these, much work was carried out by Andrews [1, 2]. With the advent of the hormone weed-killers hopes were raised that a solution to the problem might be found, and a successful experiment was carried out during the 1947 season in which significant increases in straw (and by implication in grain, which was eaten by birds) were obtained by treating sorghum growing on heavily infested land with 1 and 2 lb. per feddan[1] of MCPA as sodium salt [3]. At the time the price of grain was so low that native economy could not stand the cost of the treatment. Since then, however, the price of the chemicals has fallen, especially since the advent of 80 per cent. 2,4-D[2] (sodium salt) powder, and the price of grain has risen sharply. It was decided that the experiments were no longer of merely academic interest, and work was resumed in the 1951 season.

The spraying of weed-killers on the emergent Striga plants will give an effective kill of the parasite, but since it has by then done most of the damage of which it is capable during the course of building up its food reserves before flowering, the only benefit of the treatment is in reducing the amount of seeding. In the 1947 experiment the sorghum was sprayed with both strengths of the MCPA at 14 and 28 days after sowing before any Striga had appeared. In this manner, the MCPA was washed into the soil and killed many of the parasites before they could injure the cereal.

The three experiments to be described here were all carried out on irrigated sorghum; the first at Nuri Pump Scheme in Northern Province, the second at the Gezira Research Farm, and the third on the White Nile at Fatisa. Of these sites, the first and third were heavily infested naturally; the second had been heavily infested artificially during previous Striga experiments.

Nuri Pump Scheme

An area, 45×60 metres, was laid out in nine plots of 15×20 m. Sowing of sorghum, variety Abu Saba'in, was followed 15 days later by the spray treatments. These were:

A. 1 lb. per feddan MCPA as sodium salt.
B. 1 lb. per feddan 2,4-D as sodium salt.
C. Control, no spray.

[1] 1 feddan = 4,200 sq. metres = 1 acre approx.
[2] Also known as DCPA.

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All spray rates are calculated as equivalent weight of MCPA or 2,4-D acid. No uninfested control plots were obtainable. The dates of operations were: Sowing 15.6.51; spraying 30.6.51; harvest 25.9.51.

Striga plants first started to make their appearance on July 14, and then visible infestation increased steadily until August 19, when the plants were pulled, counted, and weighed, and removed from the plots. Results are given in Tables 1 and 2, where it will be seen that the actual incidence of Striga, by three criteria, was reduced to about one-third as a result of either treatment.

TABLE 1. *Percentage of Sorghum Holes infested with Striga at Nuri*

	Treatment		
Date	*A*	*B*	*C*
14·7	1	1	2
21·7	6	6	17
28·7	17	24	50
4·8	19	25	67
11·8	36	31	78
18·8	37	31	79

In Tables 1–3 the differences between treated and controls are highly significant. The differences between the treatments are not significant.

TABLE 2. *Fresh Striga Plants per Feddan at Nuri, pulled 19.8.51*

Treatment	*Weight*	*Numbers*
	rotls	
A	524	63,322
B	493	57,022
C	1,333	124,600

As the actual area of the experiment was smaller than the irrigable field in which it took place, the surrounding land was sown at the same time by local cultivators, with sorghum of the same variety. As it became obvious towards the end of the experiment that little or no grain could be expected, the straw was cut for fodder. That their pessimism was fully justified may be seen by reference to Table 3, in which are given the yields per feddan of sorghum under the various treatments. There were no statistical differences between the effects of the two chemicals. The yields of heads were low, but the variety is one esteemed

TABLE 3. *Yields of Sorghum at Nuri, harvested 25.9.51*

	A	*B*	*C*
No. of heads per feddan	10,920	17,682	Nil
Wt. of heads per feddan (rotls) . . .	554	594	Nil
Wt. of straw per feddan (rotls) . . .	11,700	11,240	4,496

principally for its high yield of straw, and the yield of heads was fairly comparable with that from neighbouring areas that were not locally considered too infested to be used for sorghum cultivation.

Gezira Research Farm

This experiment was designed to compare the effects of MCPA and 2,4-D sodium salts at two strengths, viz. 1 lb. and 2 lb. per feddan. Unfortunately the chemical in this case killed and severely damaged most of the sorghum plants. Re-sowings were, of course, useless for several weeks after the application of the chemical, and so the experiment was abandoned.

Spraying was carried out 14 days after sowing. After a further week it was obvious that extensive injury had been caused to the crop by all spray treatments. Plants treated at the lower rate were extensively yellowed, and many of those treated at the higher rate were either heavily burned or killed outright. After one week more, several of the plots were completely bare of crop.

The reason for this result is obscure; no other cases have come to the author's notice of such killing of sorghum by hormone weed-killers. It is, however, suspected that a contributory cause lay in the abnormally dry season. No rains had fallen in the Gezira to wet the soil before the time of sowing; the demand on the irrigation water was increased. Only light waterings could be given, and the drying power of the atmosphere was very great. The plants, at the time of spraying, were under a heavy water strain at a time of high transpiration. Under such circumstances it might be expected that the plant's uptake of the solution sprayed on its leaves would be rather high, and that its uptake of the solution washed in at the next watering would also be high. Further experiments are contemplated.

Fatisa Pump Scheme

In conjunction with the other two experiments described above, which were carried out directly by the staff of the Gezira Research Farm, it was decided by the White Nile Schemes Board to try the chemicals on some of the tenancies badly infested with Striga on the Fatisa Pump Scheme. The sorghum was sown by the tenants in the normal manner and spraying was then carried out by the agricultural staff using knapsack sprayers. Most of the sorghum was of the Feterita variety, with the exception of a pair of tenancies on which was grown Wad Fahl.

As the tenant's holding of 2½ feddans was in most cases the unit of treatment, the only comparison available was usually between it and the untreated holding (belonging to another tenant with possibly different standards of cultivation) alongside. At harvest, a measured area of 1 feddan was cut within the treated area and compared with the yield from a similar feddan from the neighbouring untreated holding. Since the treated holdings were widely scattered, and since dates of sowing and spraying varied widely, the best guide to the relative yields is given by the yield of the treated plot as 'percentage of control'.

Yields are given in Table 4. The variety was Feterita except in Hoshas 262 and 261 where the Wad Fahl variety was grown. With much Feterita an economic increase in yield was obtained, in addition to a reduction in the amount of infestation. In no case was the increase in the yield of Feterita heads less than 9·6 per cent., representing 138 rotls,[1] and in straw of 9·2 per cent., representing 362 rotls. These two lowest increases were obtained at the highest rates of spray, possibly as a result of damage from the spray. The yield of the Wad Fahl variety was severely reduced. This appeared in the field to be partly the result of actual damage by the chemical, resulting in early lodging and thinning of the stand, and partly due to severe aphid attack (to which this late-maturing variety is rather prone), the insects being apparently more partial to the treated plants.

It appears that the best results in this experiment were obtained at the 1½–2 lb. rate per feddan of the 80 per cent. material, i.e. between 19 and 26 oz. of 2,4-D acid equivalent, and that good control of the Striga, at

TABLE 4. *Data of Fatisa Experiment*

Hosha no.	*Rate in lb.p.f.**	*Sowing date 1951*	*Sprayed days after sowing*	*No. of heads per feddan*	*Wt. of heads r.p.f.*	*Wt. of straw r.p.f.*	*Striga % holes*
263	¾	1.9	20	24,120	1,087	2,195	1·1
264	0	1.9	..	23,019	860	1,532	42·6
Yield as % of control			..	104·8	126·5	143·2	3
262†	1½	1.9	20	28,370	2,970	5,544	1·0
261†	0	1·9	..	47,720	5,335	5,674	8·2
Yield as % of control			..	59·5	55·7	97·7	12
135	1½	28.7	28	16,452	1,025	3,481	14·0
135	0	28.7	..	8,800	443	3,018	55·7
Yield as % of control			..	187·0	231·3	115·3	25
324	2	6.8	14	43,754	1,566	3,729	16·3
323	0	6.8	..	31,740	1,030	1,773	75·9
Yield as % of control			..	137·9	152·0	210·3	21
249	2	30.7	35	24,210	1,101	3,760	25·9
248	0	30.7	..	13,430	569	2,072	46·5
Yield as % of control			..	180·3	193·6	181·5	55·7
250	2½	30.7	34	15,928	1,613	4,285	27·5
251	0	30.7	..	40,200	1,140	3,922	50·8
Yield as % of control			..	39·6	141·5	109·2	54·1
325	2½	6.8	14	40,639	1,572	4,276	20·0
326	0	6.8	..	15,870	1,434	3,668	94·0
Yield as % of control			..	256·1	109·6	116·6	21·7

'No. of heads' is a very variable estimate of yield, as the effect of closer spacing is to produce more and smaller heads, though the weight remains roughly constant over a considerable range of spacings. Note in particular Hoshas 250–1 and 325–6.

* In this instance the spray rate was calculated on the commercial 80 per cent. sodium salt. The actual rate of application, calculated as acid, was only 80 per cent. of the amount shown.

† Wad Fahl variety.

[1] 1 rotl = 450 gm. = 1 lb. approx.

least in terms of the percentage of infested holes, was obtained as a result of all times of spraying up to 28 days. In general the later the date of spraying the lower the degree of control obtained.

Discussion

It seems that a satisfactory solution to the Witchweed problem may at last be in sight, at least as far as certain varieties of dura are concerned. Varieties of sorghum which, like Wad Fahl, seem to be intolerant of the hormone sprays, will have to be reserved for clean ground, but the rest, such as Feterita and Abu Saba'in, will not only yield an economic crop, but will show an increase in yield such as will pay the cost of the spraying during the same year. Clean ground with no Striga is, of course, the ideal aim, and it is not impossible that by a consistent policy of spraying every grain crop in a rotation the incidence of Striga may be progressively reduced to somewhere near that point, especially if seeding of the surviving parasites can be prevented.

The anomalous result given by the Gezira Research Farm experiment requires considerable study. The probability seems to be that it was the result of a combination of unusual conditions, but should it be, as suspected, the result of the plants' treatment at a time of heavy water strain, caution is indicated in the application of the method to crops grown not under irrigation but under rainfall, where the liability to drought is much greater.

Summary.—Three experiments are described which were carried out in the Sudan in 1951 against *Striga hermonthica* Benth.

Two of these gave excellent control of the parasite as a result of spraying the sorghum host crop with hormone weed-killer between 14 and 28 days of sowing. Less satisfactory control was obtained as a result of spraying at 35 days after sowing. Not only were fewer holes infested on the treated plots but appreciable increases in grain and straw yield were recorded.

The third experiment was a failure, the sorghum being killed by the weed-killer.

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FERTILIZER PLACEMENT FOR CEREAL CROPS

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DURING the past 30 years much evidence [1–14] has been obtained to show that the combine-drilling of cereal seed and fertilizers, particularly superphosphate, produces higher yields than broadcasting. There is, however, still some doubt at what rates nitrogenous and potassic fertilizers, either alone or in combination with superphosphate, can be safely drilled with cereal seed. The experiments here recorded were made to elucidate this point and to find out if drilling is the better method of application.

Experimental

Soils and climate.—During the period 1943–9 over 70 experiments were carried out at centres selected to represent varying soils and drainage conditions in north-east Scotland. Three of these experiments were laid down on soils derived from marine sand and three on peaty land. All the others were on soils formed from glacial drifts of varying geological origin, including Old Red Sandstone, acid igneous, basic igneous, and metamorphosed rocks (*v.* Soil Associations, Macaulay Institute Reports, 1939–48). In texture the latter are light to clay loams. At all centres the soils were acid with pH values ranging from 4·9 to 6·4 and with readily soluble lime-contents between 0·035 and 0·59 per cent. CaO. The values for phosphate and potash soluble in 2·5 per cent. acetic acid (20 gm. soil+800 ml. acetic acid shaken for 2 hrs.) ranged from 1 to 20 mg. P_2O_5 and 3 to 14 mg. K_2O per 100 gm. air-dry soil.

The climate of the area may be described as moderately humid and temperate. The annual rainfall is normally between 30 and 35 in. and is relatively uniformly distributed throughout the year. The amount falling from April 1 to August 31 ranged from 8·90 in. in 1947 to 17·24 in. in 1948. The maximum air-temperature in summer is seldom above 27° C. whilst the lowest winter figures are about −18° C., the mean daily temperatures generally being between 3° and 13° C.

Field technique.—Two methods of applying fertilizers were investigated, viz. broadcasting immediately before sowing and combine-drilling with the seed. Ammonium phosphate and one of the 1946 NPK mixtures were in granular form, but with these two exceptions all fertilizers were in commercial-powder form. Appropriate basal dressings of fertilizers other than those under test were applied where necessary. The number of treatments in individual experiments varied from 5 to 36, and these were arranged according to modern statistical requirements in either randomized-block or factorial designs.

Experiments were normally laid down during March and April depending on weather and soil conditions. Throughout, an Australian 'Shearer' combine-drill machine was used to sow the seed and place the fertilizers. The crops were allowed to grow to maturity and in harvesting due allowance was made for edge effects. All the plots in an experiment

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were cut at the same time irrespective of slight differences in ripening. The produce was threshed to obtain the yield of grain for each plot, and in most cases yield data for straw were also recorded.

Laboratory analyses.—In the 4 experiments carried out in 1949 the plants in 9 of the treatments were sampled at regular intervals to study the effects on their composition during growth of broadcast and combine-drill applications of sulphate of ammonia, superphosphate, muriate of potash, and 40 per cent. potash salts.[1] Selected leaves and portions of the stems were extracted with Morgan's reagent and the amounts of ammonium and nitrate nitrogen, phosphate, and potash in these extracts were determined.

Selected samples of mature grain and straw were analysed for nitrogen, phosphate, potash, and lime. The nitrogen was determined by the Kjeldahl method; phosphate, potash, and lime were determined in a hydrochloric-acid ash-extract, the ashing being carried out at 450° C.

Results

Sulphate of ammonia.—Broadcast and drill applications of S/A at rates supplying between 11 and 34 lb. N per acre were compared at 25 centres, 23 on oats and 2 on barley. Although drilling produced no obvious reduction in the number of seeds that germinated, it tended to delay brairding for about 3 to 4 days. This effect was more obvious at the higher than at the lower rates of application. It was also affected by the rainfall after sowing; for instance, in 1944, when the rainfall during April was quite high, drilling did not retard brairding, but under the dried conditions in 1945 and 1946 the delay was quite marked. However, any delay in brairding was quickly overcome and observations made during the growing-season showed that there were generally no marked differences in growth between the two methods.

The mean grain yields are recorded in Table 1. Since the crop at one of the 1944 centres was badly lodged the data for this experiment are not included. Except for the two barley centres in 1949 the results show significant responses to broadcast sulphate of ammonia. With 17–20 lb. N per acre in 1944 drilling produced a significantly higher yield, but at two other centres it was significantly inferior. With these exceptions there were no marked differences in the grain yields between the two methods. At the heavier rate there was a small but consistent tendency for drilling to produce slightly lower grain yields, particularly in 1947. The difference between the two methods in that year is attributable mainly to one experiment.

The data for straw show that at the 17–20 lb. N rate, drilling consistently produced slightly more straw, and from the overall means, recorded in Table 6, it can be seen that the difference between the two methods is just significant. At the heavier rate, drilling produced less straw, but the difference between the mean yields in Table 6 is not significant.

[1] For brevity's sake the following contractions are used in some places: S/A, super, M/P, and P/S.—Edit.

TABLE 1. *Effect of Sulphate of Ammonia on Yields of Oat and Barley Grain*

Year	Crop and no. of expts.	No nitrogen	Broadcast		Drilled		S.E.[1] ±
			17–20 lb. N	30–34 lb. N	17–20 lb. N	30–34 lb. N	
1944	Oats (1)	16·1[2]	18·3	24·3	21·1	23·8	0·63
1945	Oats (4)	18·2	20·4	22·8	21·0	22·3	0·68
1946	Oats (3)	22·5	25·6	28·0	25·4[3]	27·7	0·64
1947	Oats (4)	(14·0)[4]	17·7	21·5[5]	17·6	19·2[5]	0·38
Mean	Oats (12)	..	19·5	23·8[6]	20·4[7]	22·7[6]	0·28
1947	Oats (5)	(13·7)[4]	20·1	..	20·4	..	0·34
1948	Oats (3)	13·7	16·7	..	16·4	..	0·28
1949	Oats (2)	15·8	18·0	..	17·6	..	0·57
Mean	Oats (22)	..	19·0	..	19·3[8]	..	0·18
1949	Barley (2)	22·6	23·8	..	22·4	..	0·58
Mean	Oats and Barley (24)	..	19·6	..	19·7	..	0·17

[1] S.E. of single mean.
[2] Throughout fertilizer rates and yields as cwt. oven-dry produce are on an acre basis.
[3] S.E. = ±0·46.
[4] Mean of no fertilizer plots S.E. = ±0·35 and 0·67 respectively.
[5] S.E. = ±0·66.
[6] S.E. = ±0·36.
[7] S.E. = ±0·26.
[8] S.E. = ±0·17.

Superphosphate.—Experiments with super (18 per cent. P_2O_5) at rates supplying 12·5 to 65 lb. P_2O_5 per acre were carried out at 42 centres, 38 on oats and 4 on barley. Placing this fertilizer in contact with oat and barley seed produced no obviously harmful effects on germination although it occasionally delayed brairding. In all experiments the plots with drilled superphosphate produced a larger and more vigorous growth during May and early June. The crops in these plots generally formed ears and ripened earlier, particularly on soils showing a large response to phosphate.

The yield data for grain are given in Table 2. The overall means for the period 1943–7 show that the broadcast application of a medium dressing of 25–30 lb. P_2O_5 per acre did not produce a significant response, but that the yield with the heavier rate is significantly greater than those for the medium and no-phosphate treatments. Combine-drilling 25–30 lb. P_2O_5 per acre produced a yield just significantly greater than that from double the amount broadcast, and markedly greater than that for the same rate broadcast. Except with barley in 1949, when there were no significant effects, drilled superphosphate has consistently produced higher yields. The results for the 1947–9 experiments show that the benefit obtained from drilling this fertilizer is not affected by placing S/A along with it except in two experiments where the latter reduced the response to the former. There is no indication of any interaction between super and M/P when these two fertilizers are combine-drilled.

TABLE 2. *Effect of Superphosphate on Yields of Oat and Barley Grain*

Year	Crop and no. of expts.	No P_2O_5	Broadcast			Drilled				S.E. ±	
			25–30 lb. P_2O_5	40–60 lb. P_2O_5	Mean	12·5–15 lb. P_2O_5	25–30 lb. P_2O_5	40–60 lb. P_2O_5	Mean	Rates	Mean
1943	Oats (9)	22·5	23·0	25·0	24·0	..	24·6	25·7	25·2	0·50	0·35
1944	Oats (9)	12·0	12·5	13·5	13·0	..	13·7	14·9	14·3	0·26	0·18
1945	Oats (3)	22·0	21·9	21·5	21·7	22·4	23·2	..	22·8	0·60	0·43
1946	Oats (3)	21·6	20·6	21·3	20·9	..	21·8	..	21·8[1]	0·83	0·59
1947	Oats (4)	15·4	16·0	17·1	16·6	17·9	19·4	..	18·6	0·66	0·47
Mean	Oats (28)	18·7	18·8	19·7	19·2	..	20·5	..	20·5[2]	0·27	0·19
1947	Oats (5)	(13·7)[3]	..	19·2	19·2	..	..	21·0	21·0	0·30	0·30
1948	Oats (3)	14·1	..	15·8	15·8	..	16·9	..	16·9	0·28	0·28
1949	Oats (2)	17·0	..	16·4	16·4	..	..	18·0	18·0	0·57	0·57
Mean	Oats (38)	..	..	..	18·4	..	..	..	19·8[4]	..	0·15
1943	Barley (1)	22·4	23·3	24·9	24·1	..	24·2	25·0	24·6	1·04	0·73
1945	Barley (1)	11·1	12·6	14·5	13·0	15·1	16·5	..	15·8	0·50	0·35
1949	Barley (2)	22·6	..	23·6	23·6	..	..	22·4	22·4	0·58	0·58
Mean	Barley (4)	..	..	..	20·2	..	..	..	20·9	..	0·33
Mean	Oats and Barley (42)	..	..	..	18·8	..	..	..	20·1[5]	..	0·14

[1] S.E. = ±0·83.
[2] S.E. = ±0·22.
[3] Mean of no fertilizer plots, S.E. = ±0·67.
[4] S.E. = ±0·17.
[5] S.E. = ±0·15.

The data for straw show practically the same effects as those for grain, and with oats the overall mean for drilling (given in Table 6) is significantly greater than that for broadcasting.

Muriate of potash and 40 per cent. potash salts.—In 1947 M/P at rates supplying 30 and 60 lb. K_2O per acre was used in 5 experiments and in 1948 P/S at the rate of 30 lb. K_2O per acre in 3 experiments. In 1949 drill applications of both fertilizers at the rate of 45 lb. K_2O per acre were compared at 4 centres with M/P broadcast at the same rate. Drilling both M/P and P/S had no obvious effects on brairding. During May and early June this method generally produced a larger growth but later in the season there were no differences.

TABLE 3. *Effects of Muriate of Potash and 40 per cent. Potash Salts on Yields of Oat and Barley Grain*

Year	Crop and no. of expts.	No potassium	Muriate of potash		40% potash salts		S.E. ±
			Broadcast	Drilled	Broadcast	Drilled	
1947	Oats (5)	(13·7)[1]	19·3	19·6	..	..	0·39
1948	Oats (3)	15·1	..	..	16·7	14·9	0·28
1949	Oats (2)	15·6	17·3	18·5	..	17·2	0·66
1949	Barley (2)	22·6	23·3	22·6	..	23·1	0·66

[1] Mean of no fertilizer plots, S.E. = ±0·67.

The results for grain are recorded in Table 3. In 1947 the yields show no significant differences between the two methods of applying muriate of potash. In 1948 broadcasting P/S gave a significant increase in yield, but drilling produced no increase and was markedly inferior to broadcasting. In 1949 with barley there were no significant effects, and with oats the only significant difference was between the no-potash and drilled M/P treatments. With both oats and barley in 1949 drilling S/A and P/S salts together, at rates supplying 20 lb. N and 45 lb. K_2O per acre respectively, produced a lower grain yield than drilling them separately. The mean data for straw (given in Table 6) are typical of the results obtained, which show no significant differences between the two methods of applying both fertilizers. There is also no reduction in the yield of straw when S/A and P/S are drilled together.

NP fertilizers.—Mixtures of S/A and super were used in 18 and ammonium phosphate in 2 experiments. The latter was applied at rates ranging from 1 to 3 cwt. per acre. From 1944 to 1946 the mixtures, which were factory-made, contained 4 to 5 per cent. N and 12 to 13 per cent. water-soluble P_2O_5, and were applied at rates ranging from 2 to 6 cwt. per acre. From 1947 to 1949 the S/A in the mixtures, which were prepared in the field, supplied 20 lb. N per acre. The amounts of superphosphate in the broadcast mixtures supplied 40 lb. P_2O_5 per acre in 1947, 60 lb. P_2O_5 in 1948, and 50 lb. P_2O_5 in 1949. The drilled mixtures contained the same amounts of superphosphate in 1947 and 1949, but in 1948 only half the broadcast rate was drilled.

Although drilling NP fertilizers had no marked effects on the number

of seeds that germinated, it tended to retard brairding for a few days, particularly at the heavier rates of application. Any delay in brairding, however, was soon overcome and during the second half of May and in early June the plots with drilled fertilizer always appeared superior to, and had taller plants than those with the same dressing broadcast. This difference gradually became less obvious during June, and from the end of that month until harvest there were often no marked differences in growth.

TABLE 4. *Effects of NP Fertilizers on the Yield of Oat Grain*

Year and no. of expts.	*No N or P*	*NP broadcast*	*NP drilled*	*S.E.* ±	
				N_0P_0	*NP*
1944 (2)	10·2	14·9	14·9	0·62	0·44
1945 (4)	19·8	24·8	25·2	0·41	0·29
1946 (2)	26·8	29·9	30·6	0·53	0·38
1947 (5)	13·7	19·2	21·6	0·67	0·47
1948 (3)	11·8	16·4	17·5	0·49	0·49
1949 (2)	16·0	17·5	18·6	0·99	0·99
Mean	16·4	20·4	21·4	0·26	0·23

Since there have been no significant effects of the rate of application, only average data for comparable levels are given for grain in Table 4. The application of fertilizer produced marked increases in the yield of grain, and although the results show no significant differences between broadcasting and drilling in any one year, the overall mean for the latter is significantly higher than that for the former. The data for straw are similar and the means in Table 6 show that drilling produces more straw.

NPK fertilizers.—Experiments were carried out at 14 centres to compare broadcast and combine-drill applications of these fertilizers made from S/A, super, and M/P. In 1944 a fertilizer with the percentage composition N 5, water-soluble P_2O_5 10, insoluble P_2O_5 6, and K_2O 5, was used at rates of 2 and 4 cwt. per acre in one experiment with oats. In 1945 and 1946 a mixture containing (per cent.) N 6, water-soluble P_2O_5 12, insoluble P_2O_5 1, and K_2O 12 was used at rates of 3 to 5 cwt. per acre at 7 centres with oats and 1 centre with barley. At 3 of the 1946 centres drill applications of this fertilizer in granular and powder forms were compared. At other 3 centres in 1946 broadcast and drill applications of 6 cwt. per acre of a fertilizer containing (per cent.) N 4, water-soluble P_2O_5 10, insoluble P_2O_5 6, and K_2O 5, were studied. In 1947, 5 experiments on oats were carried out with two mixtures, one supplying 20 lb. N, 40 lb. P_2O_5, and 30 lb. K_2O per acre, and the other the same amounts of nitrogen and phosphate but double the amount of potash.

The effect of NPK fertilizers on germination and growth are practically the same as those outlined above for NP fertilizers, drilling tending to delay brairding but producing a larger growth during the second half

of May and in early June. The data for grain are recorded in Table 5 and show marked responses to fertilizer. With oats at the 3 cwt. rate in 1944, '46, and '47, drilling produced higher yields of grain. In 1945 5 cwt. broadcast gave the highest yield, but in 1946 4 cwt. drilled was best. In the latter year 5 cwt. drilled produced a significantly lower yield than 4 cwt. drilled. At the one barley centre there were no significant differences between rates and methods of application. The mean data for the granular fertilizer in 1946 are not significantly different from those obtained with the powder form. The yields produced by 6 cwt. per acre of the mixture containing 4 per cent. N and 5 per cent. K_2O were the same for both methods.

TABLE 5. *Effects of NPK Fertilizers on Yields of Oat and Barley Grain*

Year	Crop and no. of expts.	No N, P, or K	Broadcast		Drilled			S.E. ±
			2½–3 cwt.	5 cwt.	2½–3 cwt.	4 cwt.	5 cwt.	
1944	Oats (1)	16·1[1]	18·8	..	20·6	..	..	0·71
1945	Oats (2)	13·0	..	22·2	18·8	21·0	20·6	0·53
1946	Oats (5)	26·3	29·2	31·0	32·1	32·6	29·6	0·63
1947	Oats (5)	13·7[2]	19·0	..	21·7	..	..	0·47
1946	Barley (1)	26·8	30·8	31·5	30·3	32·5	31·8	1·01

[1] S.E. = ±1·00. [2] S.E. = ±0·67.

The data for straw in Table 6 show that combine-drilling always produces higher yields, and except for the 5 cwt. rate in 1946, the weight of straw increases concomitantly with the rate of fertilizer drilled. The 1946 results show that drilling 5 cwt. of a mixture containing 6 per cent. N and 12 per cent. K_2O produced less straw than 4 cwt. As with NP fertilizers, there was a consistent tendency for drilled NPK mixtures to increase the ratio of straw to grain.

TABLE 6. *Mean Yield Data for Oat Straw*

Fertilizer	Rate per acre	No. of expts.	Broadcast	Drilled	S.E. ±
Sulphate of ammonia	17–20 lb. N	14	24·7	25·6	0·31
Sulphate of ammonia	30–34 lb. N	6	27·5	25·9	0·72
Superphosphate	All rates	26	23·3	24·8	0·24
Muriate of potash	60 and 45 lb. K_2O	5	23·0	23·4	0·61
40% potash salts	30 lb. K_2O	3	27·5	26·9	0·49
NP	All rates	13	23·1	25·6	0·36
NPK	3 cwt.	10	24·8	27·8	0·46
NPK	5 cwt.	7	27·8	29·4	0·56

Composition.—As indicated earlier, the plants in 9 treatments of the 1949 experiments (2 on oats and 2 on barley) were sampled at regular intervals during the growing season. Variable amounts of nitrate nitrogen ranging from 0 to 0·2 per cent. were found in the fresh matter of

both lamina and stem in the samples taken in May. The percentages of ammonium nitrogen ranged from about 0·02 in some of the May samples to 0·002 in the August ones. Neither the nitrate nor ammonium values show any differences attributable to the two methods of applying S/A, super, M/P, or P/S.

The mean data for phosphate and potash are given in Table 7. With S/A the percentages of phosphate in the mid-May samples of both lamina and stem were higher with drilling. The individual results show that this was the case at three centres but not at the fourth. With super, drilling gave higher percentages of phosphate in both lamina and stem in the mid-May sampling, but at the end of May there were no differences. In mid-June there was a tendency for broadcast super to give higher phosphate percentages than the drilled. With M/P at the mid-May sampling, drilling produced higher percentages of potash in both lamina and stem, and the figures for P/S are similar.

It was not possible to analyse all the samples of grain and straw but a large number of selected treatment samples were examined from each series of experiments. The mean results for oat-grain ranged in percentages from 1·34 to 1·82 N, 0·66 to 1·00 P_2O_5, 0·48 to 0·62 K_2O, and 0·09 to 0·12 CaO, whilst the data for oat-straw ranged from 0·24 to 0·39 N, 0·07 to 0·22 P_2O_5, 0·60 to 1·77 K_2O, and 0·23 to 0·38 CaO. However, the composition of the produce showed no marked or consistent differences attributable to the two methods of applying the various fertilizers.

Discussion and Conclusions

Since the composition of the mature produce is the same for both methods, the yield data can be used directly to compare the effectiveness of broadcast and drill applications. It must, however, be remembered that the differences in final yield may be largely associated with the effects of the fertilizers on early growth. Brenchley [15] demonstrated that barley can take up all the phosphate it needs during the first six weeks of growth, and since placing superphosphate allows the crop to take up its phosphate more quickly, this may be the reason why drilling this fertilizer is superior to broadcasting it.

The results show that generally sulphate of ammonia can be safely drilled with oat-seed at rates up to about 1½ cwt. per acre, and will produce yields similar to those obtained by broadcasting. It does not appear advisable to combine-drill this fertilizer at heavier rates. The only advantage from drilling is a possible saving in labour by sowing seed and fertilizer in one operation. Heavier dressings of S/A can be drilled with oats in Scotland than Hanley [16*b*] has suggested. He did not recommend more than ½ cwt. per acre.

The results illustrate quite clearly that super should be combine-drilled to obtain full benefit from the phosphate, and that 25–30 lb. P_2O_5 drilled is at least as effective as double that amount broadcast. These findings agree with those of Crowther [2] and Hanley [16*a*] and with American and Australian work. Combine-drilling superphosphate is, therefore, one way of helping to reduce the effects of the present

TABLE. 7. *Effect of Sulphate of Ammonia, Superphosphate, and Muriate of Potash on the Composition of Oat and Barley Plants at Different Stages of Growth, 1949*

(*Mean percentages in fresh matter*)

Date of sampling	*Part of plant analysed*	*Sulphate of ammonia 20 lb. N*				*Superphosphate 50 lb. P_2O_5*				*Muriate of potash 45 lb. K_2O*			
		Broadcast		*Drilled*		*Broadcast*		*Drilled*		*Broadcast*		*Drilled*	
		P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Mid-May	Lamina	0·057	0·40	0·066	0·43	0·055	0·41	0·068	0·40	0·062	0·36	0·061	0·47
Mid-May	Stem	0·046	0·35	0·051	0·34	0·044	0·36	0·054	0·34	0·049	0·30	0·048	0·40
End-May	Lamina	0·048	0·42	0·051	0·39	0·051	0·42	0·048	0·39	0·050	0·39	0·049	0·42
End-May	Stem	0·048	0·42	0·050	0·40	0·052	0·43	0·048	0·39	0·050	0·41	0·051	0·42
Mid-June	Lamina	0·050	0·34	0·050	0·35	0·053	0·36	0·046	0·32	0·048	0·34	0·051	0·35
Mid-June	Stem	0·049	0·29	0·049	0·28	0·052	0·32	0·046	0·26	0·048	0·30	0·051	0·28
Mid-July	Stem	0·059	0·23	0·061	0·25	0·060	0·25	0·059	0·23	0·060	0·23	0·059	0·26
Mid-August	Stem	0·031	0·31	0·030	0·28	0·026	0·27	0·033	0·30	0·029	0·29	0·032	0·30

shortage of this fertilizer. Alternatively, higher yields could be expected if phosphate were drilled instead of broadcast on land deficient in this nutrient.

Although the results for the two potassic fertilizers are not adequate for drawing definitive conclusions, they do indicate that it is safe to combine-drill up to about 1 cwt. per acre M/P. This finding agrees with the work of Crowther [2] and Nicholson [8] since placing muriate of potash with oat and barley seed does no harm, but differs because it shows no marked benefit from drilling. The main reason for this appears to be that the soils on which the present series of experiments was carried out are not so deficient in potash as those on which the English work was done. The data indicate that, at the rates used in the present experiments, it may be harmful to drill 40 per cent. P/S and a mixture of this fertilizer and S/A. The reason for this is not clear, but it is probably because the P/S contain an appreciable amount of sodium chloride, which would increase the salt concentration in the soil solution more than potassium chloride.

With NP fertilizers it is quite safe to combine drill mixtures made from S/A and super at rates supplying up to about 30 lb. N and 80 lb. P_2O_5 per acre. Although the difference in grain yield between the two methods is not large, drilling has consistently produced higher yields than broadcasting and is, therefore, a more effective method of application. These findings are in general agreement with those of Lewis and Strickland [4], but do not show such large differences in favour of drilling. These workers used fertilizers supplying the same amounts of nitrogen and phosphate, whereas the mixtures used in the present experiments contained more phosphate than nitrogen. It is quite possible that a larger difference would have been found between the two methods under Scottish conditions if the NP fertilizer used had supplied the same amounts of nitrogen and phosphate. In the present experiments there is a small but consistent tendency for drilling NP fertilizers to increase the ratio of straw to grain, but since this increase is relatively small it seems to be of little practical importance except on soils where serious lodging is likely to occur.

Ammonium phosphate has been combine-drilled with oats at rates up to 3 cwt. per acre without any obviously harmful effects. This is about double the rate suggested by Hanley [16*b*]. The yields, however, show no benefit from drilling.

The number of experiments with NPK fertilizers is not large enough to warrant definitive conclusions. It seems that up to 4 cwt. per acre of a mixture containing 6 per cent. N and 12 per cent. K_2O can be safely drilled with oat-seed, and that 3 to 4 cwt. drilled will produce yields similar to 5 cwt. broadcast. It appears that as the percentages of N and K_2O in the fertilizer decrease the rate at which it can be safely combine-drilled can be increased. This conclusion agrees with the findings of other workers [4, 16*b*] in showing that it may be harmful to combine-drill fertilizer mixtures containing relatively large amounts of S/A and M/P.

Since drilling S/A sometimes tends to produce lower yields than

broadcasting, and occasionally reduces the response to drilled super, it may be that the safest and most reliable method of fertilizing cereals would be to combine-drill the phosphate and potash and broadcast the nitrogen later. Watson [17] showed in pot experiments that delaying the application of nitrogen until a few weeks before earing may not affect the increase in grain due to fertilizer but may reduce the increase in straw. It may be possible, therefore, to increase the yields of spring-sown cereals by applying part of the nitrogen at sowing-time and the remainder a few weeks before earing. Field experiments are being carried out to test this point.

The only noteworthy effect of soil type in the present experiments is that the two in which drilling S/A gave significantly lower grain yields than broadcasting were on soils of basic igneous parent-material. Another feature is that the benefits of drilled super are generally greatest on phosphate-deficient soils. This is in agreement with the findings of other workers [5].

Summary

During 1943–9 over 70 experiments were carried out on oats and barley to compare broadcast and combine-drill applications of various fertilizers. The results show that S/A can be safely drilled with oat-seed at rates up to about 1½ cwt. per acre and, with few exceptions, the yields of grain are the same for both methods. Drilling super is more effective than broadcasting it, and 25–30 lb. P_2O_5 per acre drilled produces yields at least as good as double the amount broadcast. M/P can be placed at rates up to 1 cwt. per acre with the seed, but the present experiments show no significant benefit from drilling. It appears that P/S should not be placed with cereal seed, particularly if S/A is drilled along with it.

Mixtures of S/A and super can be safely drilled at rates supplying up to 30 lb. N and 80 lb. P_2O_5 per acre respectively. Although the difference between the two methods is not large, drilling consistently produces slightly higher yields. It appears that up to 4 cwt. per acre of an NPK mixture made from S/A, super, and M/P, and containing 6 per cent. N and 12 per cent. K_2O, can be placed along with cereal seed. Drilling 3 to 4 cwt. of this mixture produces yields similar to 5 cwt. broadcast. As the percentages of N and K_2O in the fertilizer decrease the rate at which it can be safely drilled can be increased.

Placing superphosphate seems to allow the crop to take up its phosphate more quickly during early growth, and this may be the reason why drilling this fertilizer is superior to broadcasting it. There are no differences in the contents of N, P_2O_5, K_2O, and CaO in the mature grain and straw attributable to the two methods of application.

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THE EFFECT OF SEED-RATE ON YIELD OF CEREALS

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Introduction.—Small groups of cereal trials with different seed-rates are to be found scattered throughout the reports of experimental farms and county trials from 1900 onwards; a few trials are at present being undertaken by the N.A.A.S. (National Agricultural Advisory Service). These new trials are an indication of the long-standing interest of farmers and their advisers in the question of how much seed is likely to give the best return per acre. Unfortunately this interest has usually survived for only one or two seasons: frequently the experimenter failed to obtain a definite result and abandoned the project, or, having obtained what appeared to be a positive answer, seems to have regarded further experiments as unnecessary.

Following the work of Engledow (39–42) and his fellow workers at Cambridge, Hudson (43) did much to put the study of competition in a cereal crop on a scientific basis. In this last paper Hudson summarized much of the experimental information on the optimum seed-rates in Australia and in different parts of the United States, but referred to only two English experiments. This note summarizes the results of all the experiments carried out in the British Isles which could be traced in the literature; the total numbers for the different cereal crops were as follows: winter wheat 18; spring wheat 3; spring barley 16; spring oats 110.

The great majority of the trials were of a simple type often without replication or with the treatments in duplicate. The large number of experiments for oats consists mainly of numerous simple trials over small ranges of seeding which were carried out in Scotland early in the century.

Experimental Results

The individual results of the experiments on winter wheat and spring barley are shown in Figs. 1 and 2, together with a curve to show the average effect on yield of changes in seed-rate derived from all comparable experiments. The numbers attached to each experiment indicate the sources of the data given in the Appendix. The average curves are based on deviations, computed at half-bushel intervals, from the average yield at a standard rate of sowing (2 bu. per acre). For this purpose the individual points given by each experiment were joined up by straight lines as in Figs. 1 and 2, making it possible to interpolate between two yields at, say, 1 and 2 bu. per acre and obtain an estimated yield at 1½ bu. per acre. Using the interpolated values where necessary, the average yield of wheat at 1½ bu. per acre was obtained only from those experiments giving information at both 1½ and 2 bu. per acre, whilst the yield at 1 bu. per acre was obtained from the difference in

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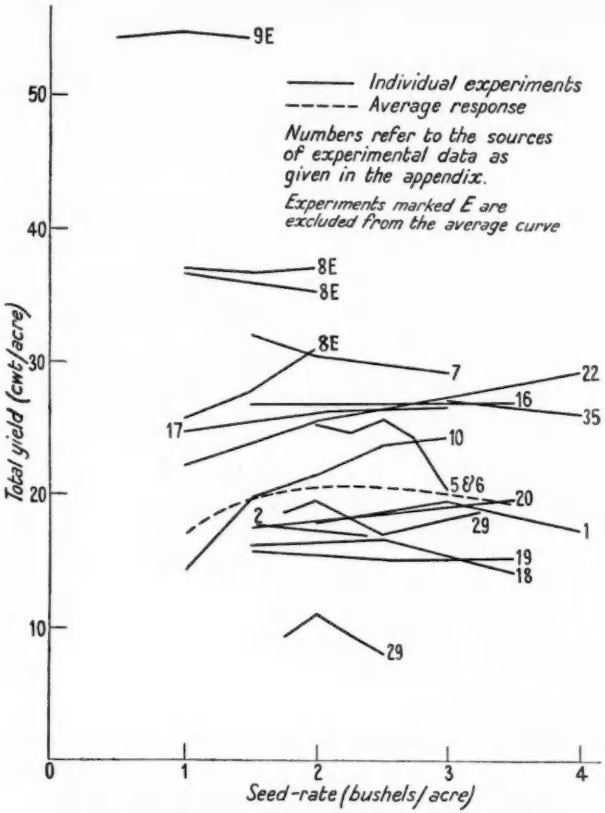

FIG. 1. Effect of seed-rate on yield of winter wheat.

yield of those experiments giving information at both 1 and 1½ bu. per acre. Values for wheat were as follows:

	cwt. per acre
Mean yield at 2 bu. per acre (14 experiments*) . . .	20·5
Difference 2–1½ bu. per acre (9 experiments) . . .	0·8
Adjusted mean yield at 1½ bu. per acre	19·7
Difference 1½–1 bu. per acre (3 experiments) . . .	2·8
Adjusted mean yield at 1 bu. per acre	16·9

* Four experiments giving very high yield omitted (see text).

For oats the total number of experiments was much too great to allow the individual results to be shown. In Fig. 3, therefore, the average of each series of experiments has been shown. The curve representing the general average was computed as for wheat and barley except that 1-bu. intervals were taken and the standard seed-rate was 4 bu. per acre.

Wheat.—If we exclude the three experiments on fen soils (8) and one exceptionally high-yielding experiment (9) it appears that, at normal levels of yield, substantial loss of yield may result from sowing at less than 1½ bu. per acre and that the optimum seed-rate is around 2 bu. per acre. There is on the average a small loss of 0·6 cwt. per acre at 3 bu. per acre, together with the cost of the extra seed. Hudson (44), mainly using data from American and Australian sources, concluded

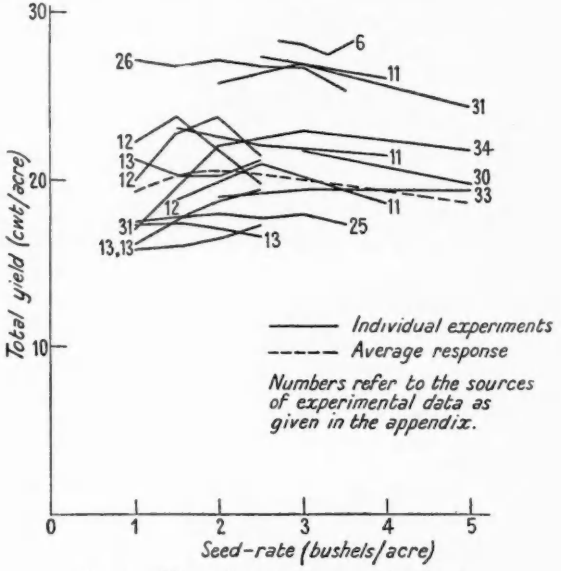

FIG. 2. Effect of seed-rate on spring barley.

that in regions of inadequate rainfall and poor natural fertility the optimum seed-rate tended to be lower than in wetter and more fertile regions. He ascribed this to the greater competition between individual plants for soil nutrients and moisture under the more adverse conditions, and went on to suggest that a similar general relationship between seed-rate and yield would obtain in this country. Such a relationship would conflict with the normal farming practice of giving only a light seeding on land of really high fertility and adding an extra bushel or two for more adverse growing conditions. Nor is it supported by Fig. 1, which shows a general tendency for the lowest seed-rate tested (1 bu. per acre) to be adequate at the highest levels of yield, whilst, in experiments with only moderate yields, higher seed-rates (up to 2 bu. per acre) seemed to be necessary.

Only one of the experiments included date of sowing as a factor as well as seed-rate, but there is no doubt that, on most soils, a heavier seeding is necessary for late November or December sowings than for sowings in September or early October.

Barley.—The barley experiments were almost all carried out on light or medium land in Norfolk, Oxfordshire, Shropshire, and Yorkshire. They show on the average a fairly well-defined optimum at about 2 bu. per acre; if allowance is made for seed sown the best yield is given by 1½–2 bu. per acre, and only a quarter of the experiments show a substantial loss in yield when as little as 1 bu. per acre is sown. Above

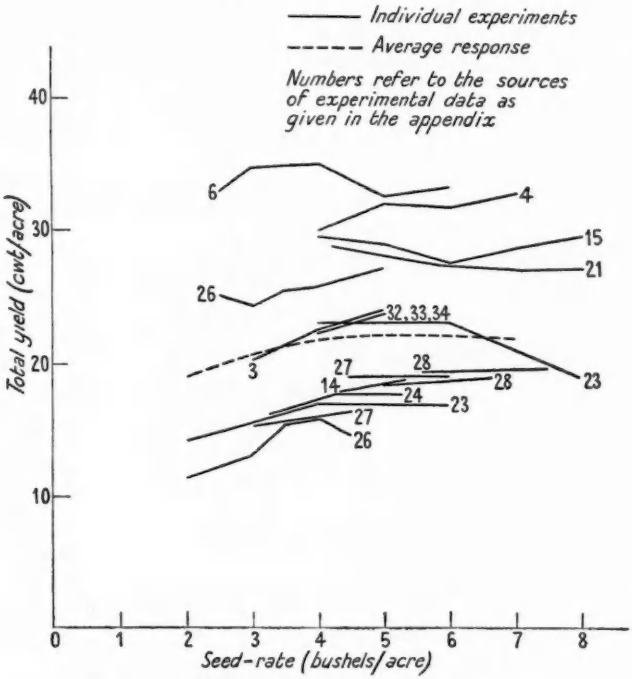

FIG. 3. Effect of seed-rate on yield of spring oats.

2 bu. per acre, a loss in yield of 0·7 cwt., is incurred for each extra bushel sown; allowing for the seed sown as before, the loss in yield at 4 bu. per acre is about 15 per cent. of the yield at 2 bu. per acre. Notes which accompanied most of the reports showed that at the lowest seed-rate the reduction of competition between individual plants produced a very coarse sample; seedings at 2–2½ bu. per acre, however, seem to have been of at least as good quality as those at higher rates. At the higher rates the individual grains tend to be rather small, and (although this was not noted by the experimenters) the liability to lodging is probably increased substantially.

Oats.—Almost all the experiments on oats were carried out in North Wales, Northern England, Scotland, and Northern Ireland. Fig. 3 indicates that the optimum seed-rate is likely to lie between 4 and 5 bu.

per acre. Most of these experiments were carried out before seed-dressing with mercurial powders became general, and they may therefore somewhat overestimate the amount of seed required. Whilst there is little direct information on the seed-rates actually adopted by farmers, 4–5 bu. appears to be the normal seeding in the drier parts of the country whereas in the wetter parts, to which these experiments mainly apply, seed-rates in excess of 5 bu. are common. These heavier seed-rates probably increase the risk of lodged crops, but at the same time they increase the amount and perhaps the feeding-value of the straw; this may be specially marked for the small-seeded varieties grown in the wetter districts.

Other Factors affecting the Optimum Seed-rate

The experimental results given in Figs. 1–3 provide a fairly satisfactory answer to the question which was in the minds of experimenters as to how *on the average* seed-rate affects yield, but the results at once suggest a number of related problems which have received little attention. The relation of seed-rate to date of sowing and its effect on lodging, the effect of spacing between the rows, and thickness of seeding in the row, on both yields and freedom from weeds, and the variation of fertilizer responses with different plant populations, are some of the factors that influence the optimum seed-rate of a cereal crop. Only a small number of experiments on these wider aspects of seed-rate have been undertaken, either in Britain or on the Continent.

Spacing between the rows closer than the normal $6\frac{1}{2}$–7 in. gave a small increase of yield in the English but not in the Danish experiments (36–38), but the total number of trials is insufficient to allow firm conclusions to be drawn. Wider spacings than normal have also been tried in a few experiments in conjunction with different seed-rates; there was no sign of any difference in yield between 7-in. rows and rows spaced at 10–12 in. for a given seed-rate per acre. Danish experiments in which the extra wide rows were hand-hoed also gave very little difference in yield. To date there appears to be no evidence that a substantial improvement in yield could be obtained by using wider or narrower spacings than normal.

Arising out of the experiments on seed-rate it would be useful to know how far the response to fertilizer varies with different plant populations. An experiment carried out at Jealott's Hill in 1935 (7), in which there was a substantial response of wheat both to increased seeding and to nitrogen, showed a marked positive interaction between the two factors, but five similar Danish experiments on barley gave practically the same nitrogen response at all levels of seeding.

More recently, five experiments have been carried out on winter wheat at Rothamsted in the years 1946–50 on land known to be infected with eyespot (*Cercosporella herpotrichoides*) (16–20). The treatments included three seed-rates and either three or four rates of application of nitrogen. There appeared to be no gain and in some of the experiments even an appreciable loss from the higher seedings in the absence of nitrogen. In the presence of a moderately heavy dressing of spring

nitrogen (0·3–0·4 cwt. N per acre) yields from the higher seed-rates exceeded those from the low seed-rate by an average of about 1 cwt. per acre; much the same result was given by the higher level of dressing (0·6–0·8 cwt. per acre). The increased response to nitrogen was, however, only sufficient to balance the extra seed required. It may well be, however, that the relationship between seed-rate and response to nitrogen is different on infected land from that on clean land; moreover, nitrogen responses are generally small for wheat at Rothamsted.

In view of the inconclusive evidence from the trials already carried out with rates of seeding and nitrogen there may be a case for further trials including these factors. A simple factorial design on 24 plots which has already been employed for winter wheat in the West Midland Province of the N.A.A.S. (9) has the following treatments: 2 sowing dates (on blocks); 3 seed-rates; 2 rates of nitrogen fertilizer.

The inclusion of time of sowing considerably increases the amount of work but is very desirable for autumn-sown cereals. In this instance there was a marked interaction of sowing-date with seed-rate, and some interaction with nitrogen. Alternatively, two varieties might be tested instead of the two sowing-dates.

A considerable number of experiments on the effect of different seed-rates have been carried out in Scandinavian countries, and whilst the differences of climate make them of little direct value it may be worth while to quote results for a set of Norwegian experiments (37) in which the percentage of the crop area lodged was noted. These experiments were carried out at Vollebaek over a number of years and (for oats) on other farms in Norway. In Table 1 figures for the lowest and highest rates only are given; the intermediate rates gave values in close agreement, indicating that the means are of considerable accuracy.

TABLE 1. *Results of Norwegian Experiments on Low and High Seed-rates*

	Years or centres	*Seed-rate cwt./acre*		*Yield (cwt. per acre)*				*% lodged*	
				Grain		*Straw*			
		Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Rye . .	6	1·0	1·6	17·4	18·4	40·6	45·2	40	53
Spring wheat .	10	1·4	2·4	15·7	16·9	30·3	33·0	10	13
Barley . .	10	1·0	1·9	19·8	20·6	21·8	25·3	1	6
Oats . .	25	1·4	2·1	20·0	20·7	30·0	31·6	21	22

In these experiments the higher seed-rates gave somewhat higher yields of grain and straw. There was an increase in the amount of lodging but seed-rate was evidently not a major factor affecting lodging.

On the other hand Glynne (43) has recently shown that, in one of the Rothamsted experiments on land infected by eyespot, there was a marked increase in the percentage of the crop lodged as seed-rate was increased.

Summary and Conclusions

The results of all available experiments carried out in the British Isles on the effect of seed-rate on the yield of cereals have been summarized, together with some data for Scandinavian countries. A substantial number of experiments were traced for winter wheat and for spring barley and oats; most of the experiments on spring oats were from the north and west of the country. The main conclusion to be drawn from the data is that the optimum seed-rates (about 2 bu. per acre for wheat and barley and 4–5 bu. per acre for oats) are considerably below those commonly in use. Whilst there are no factual data on the seed-rates normally adopted in different parts of the country, it is known that in many districts seed-rates of 3 bu. of wheat and barley are common, whilst in the wetter districts 6–8 bu. of oats are often sown. Naturally the farmer must continue to exercise his judgement to suit the circumstances of the particular field he is sowing, reducing the rate for early sown crops, and in conditions of high fertility or where take-all or eyespot is expected, and increasing the rate where soil pests are known to be present and for late sowings and rough tilths. Nevertheless, it seems likely that many farmers could effect a substantial reduction in the amount of seed sown towards the rates suggested above without loss in yield.

Information on the influence of other factors such as time of sowing, row-spacing, and nitrogen dressings was scanty. Six experiments with both seed-rate and nitrogen dressings as factors suggested that nitrogen responses increased slightly as seed-rate increased, but the greater response was sufficient only to balance the cost of the extra seed. The results of Scandinavian experiments showed a definite but small increase in the percentage of lodging with higher seed-rates. There was some indication that, for each cereal, lower seed-rates were most successful in conditions of high fertility as judged by the level of mean yield.

There seems little need for further experiments testing seed-rates alone, except perhaps on spring wheat, but simple factorial experiments including comparisons between varieties, nitrogen dressings, and perhaps sowing dates in addition to seed-rates, would indicate how far the foregoing conclusions need to be modified with respect to these factors as well as for different types of soil.

APPENDIX: SOURCES OF EXPERIMENTAL DATA

British

(1) Bedfordshire County Council, Rept. on Experiments on Wheat, 1908.
(2) Cambridge University, Ann. Rept. on Expts. with Crops and Stock, 1901–2, p. 6.
(3) Edinburgh and East of Scotland College of Agriculture, Rept. of Work for Year ending April 30, 1933, p. 64.
(4) Harper Adams Agricultural College, Rept. of Expts., 1910, p. 31.
(5) —— ibid., 1913, p. 11.
(6) —— ibid., 1914, pp. 9, 11–12.
(7) Jealott's Hill Agric. Res. Stat., Guide to Expts., 1935, p. 13.
(8) Kirton Agric. Inst., Rept. of Expts., 1927, p. 37.

temperature was plotted on a graph (vertical axis) against the mean monthly rainfall (horizontal axis) after the hythergraph method of Taylor [13]. On the resulting polygon, a big vertical distance between the extremes shows a wide variation of mean monthly temperature between hottest and coldest month, and the longer the horizontal distance between the extremes of the hythergraph, the greater the difference of mean monthly rainfall between driest and wettest month of the year (a single dot would indicate that precisely the same monthly mean of temperature and of rainfall prevail in every month of the year).

Temperature and rainfall range for the county of Ayr (referred to in the Discussion) was obtained by using climatological summaries for the years 1932–49 for 4 stations in Ayrshire: Auchincruive, Kilmarnock, Prestwick, and Turnberry, for each of which both the highest and the lowest monthly mean temperature and total monthly rainfall that had obtained in any of the 18 years was noted. The lowest figures from each station were then averaged, giving an 'average lowest', and the highest were similarly arranged to give an 'average highest'. The reason for this was to smooth out such extremes of monthly mean as had obtained perhaps only once in the course of 18 years at one of the stations. The resultant range of 'average lowest' to 'average highest' was thought to be more akin to a range for the whole of that part of the county of Ayr where Ayrshire cattle originated and are densest.

Milk records were obtained for breeds and by counties from the annual reports for the year ending October 1, 1946, of the National Milk Records of the Milk Marketing Board [14]. The breed averages were calculated from county herd averages (given separately for each breed) and weighted for number of herds; they differ slightly from the average given by the National Milk Records, which are weighted for numbers of cows.

Hythergraphs for districts of the British Isles.—These are the polygons shown in Fig. 1 for 7 districts comprising the whole of England and Wales, and the West of Scotland. The hythergraphs show that rainfall, as average monthly means, varies more from district to district than does temperature. No month in districts 2, 3, and 4 shows a rainfall of over 3 in., whilst in District 6 only 3 months have less than this. Shapes of hythergraphs for the 7 districts studied can be seen to vary appreciably from the long thin type (district 3) to the broad and short type (district 8). The assumption underlying the use of these hythergraphs is that their shape is characteristic of the climate—as represented by temperature and rainfall—for their districts; and as there may be a correlation between breed distribution and climate, there may also be one between breed distribution and shape of hythergraph.

Distribution of Pedigree Ayrshire, Friesian, and Shorthorn Females—according to Meteorological Districts and in relation to Hythergraphs

The actual numerical distribution of the registered females of these breeds is not given here, because, as stated in the introduction, primary interest centres around the question whether the climate of any district has favoured one breed rather than another. To this end the breed data were converted to a percentage basis, and expressed for each breed as a

percentage of the total registered females of the three breeds combined in each district; this is shown in Table 1, and in Fig. 1.

If the proportions of the three breeds to each other in England and

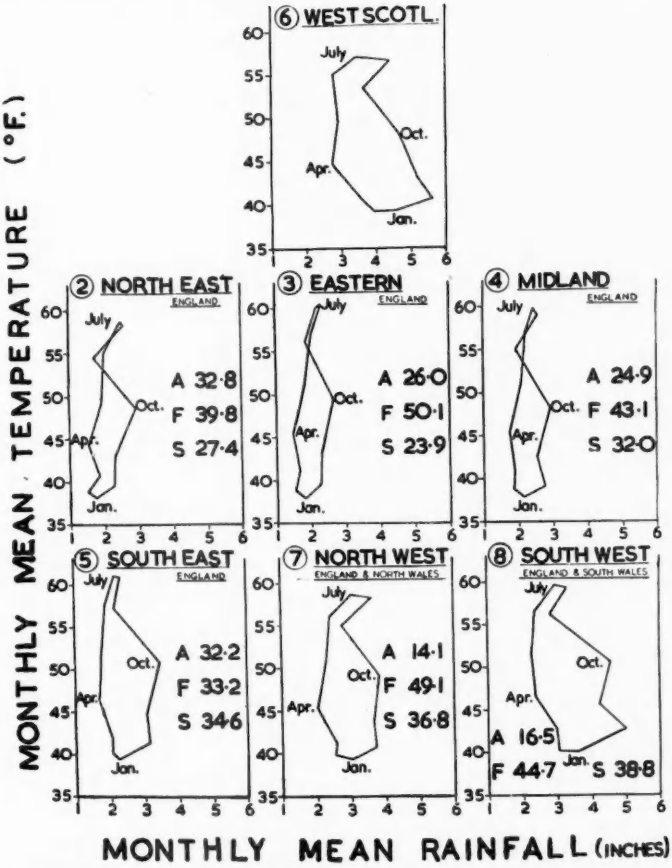

FIG. 1. Hythergraphs for seven districts of Great Britain. The figures alongside the hythergraphs show the number of Ayrshire (A), Friesian (F), and Shorthorn (S) heifers registered in 1945–6 as a percentage of all registrations of heifers of these three breeds.

Wales as a whole (24·0, 43·5, 32·5) were accepted as the proportions to be expected in each district—provided the same factors operate in each district as they do in the country as a whole—then the variable proportions in fact found might be used as a measure of inter-breed competition. The reasons for the relative success or failure of one breed in relation to others may derive from a variety and combination of causes, genetic,

environmental, economic, or due to local reputation of the breed for some other reason. The importance of any one factor may vary from district to district, and from time to time; the purpose here is only to ascertain whether climate has had any recognizable effect.

TABLE 1. *Percentage Distribution of Heifers of Three Breeds of Cattle Registered in 1945–46 in each of Six Meteorological Districts of England and Wales*

Meteorological district	*Total registered ♀♀ in each district for three breeds combined*	% *Ayrshires*	% *Friesians*	% *Shorthorns*
2. England NE. . .	2,283	32·8	39·8	27·4
3. ,, E. . .	5,118	26·0	50·1	23·9
4. ,, Midlands .	10,375	24·9*	43·1*	32·0*
5. ,, SE. . .	5,534	32·2	33·2	34·6
7*a* and *b*. NW. England, N. Wales . .	5,538	14·1	49·1	36·8
8*a* and *b*. SW. England, S. Wales. . .	4,177	16·5	44·7*	38·8
England and Wales: Total . . .	33,025	24·0	43·5	32·5

* Percentages marked with asterisk do not differ significantly (P = 0·01) from percentages based on totals; all others do (significance calculated on numbers of registrations 'expected' in each district, not on percentages given above).

It might be that a breed of livestock when it enters new territory succeeds best in relation to other breeds, and becomes most numerous in those districts which are climatically most similar to its native region—other things being equal. If this were true, and if shape and range of hythergraphs represented climates, one would expect pedigree Ayrshire cattle to have succeeded best in relation to other breeds in districts of England and Wales which show hythergraphs most akin in range and shape to that of the West of Scotland (district 6). The districts most nearly approaching such similarity with the West of Scotland are the South-west of England and South Wales (district 8) and the North-west of England and North Wales (district 7). But these are just the districts where Ayrshires are numerically weakest in relation to the other two breeds. Conversely, district 2 (NE. England) where Ayrshires have succeeded best relative to the other breeds, has a hythergraph most unlike both in range and shape that of the home of the breed (district 6).

Friesians are seen to be most numerous relative to the other two breeds in districts 3 and 7, yet the hythergraphs for the two districts differ appreciably within the range found in England and Wales. The proportion of Shorthorns, relative to the other two breeds, increases with increasing average annual rainfall—particularly winter rainfall (October–March)—from district to district. The order of the districts according to increasing average annual rainfall, and average winter rainfall, is 3, 2, 4, 5, 7, 8; this is also the order from lowest to highest in the proportion

of Shorthorns to other breeds found in these districts. One is led to speculate whether this is coincidence, or whether farmers do in fact prefer Shorthorns to either Ayrshires or Friesians for the wetter winter conditions. For Ayrshires this would appear anomalous, as the average rainfall in the West of Scotland, where Ayrshires originated, is higher than in any of the English districts. It may be, however, that in England and Wales, at least, there is a difference of purpose on the part of the Shorthorn breeders on the one hand, and of Friesian and Ayrshire breeders on the other. One breed may be treated as dual purpose to be kept under extensive conditions, the other as single purpose for intensive management. If it were found that Shorthorn numbers have declined most in the drier districts of the country, it would be more concrete evidence than that presented; it may be worth investigating this point further.

Milk Yield according to Breeds and Meteorological Districts

Although climatic differences (as represented by hythergraphs) exist between meteorological districts of the British Isles (*v.s.*), it would be difficult to decide from the evidence whether these differences have in part determined the breed distributions. It may be, however, that the differences in climate can be related to differences in milk production between districts and breeds.

The milk yields—quoted here as average herd yield of milk in lb.—published by the Milk Marketing Board [14] are for pedigree and non-pedigree stock combined; the data should not therefore be strictly related to the distributions of pedigree Ayrshires, Friesians, and Shorthorns given earlier in this paper. The average yield for each meteorological district and for each breed was calculated from the county data: the whole of Yorkshire was for this purpose included in district 2 (NE. England). The total number of herds recorded in England and Wales for the year ending October 1, 1946, were 1,303 Ayrshire, 2,722 Friesian, and 5,023 Shorthorn.

Fig. 2 shows that in all 6 meteorological districts of England and Wales, the recorded herds of Friesians had the highest average yield, and the Shorthorns the lowest. Moreover, the differences in yield between the breeds appear to have been very similar in each of the 6 districts. There are also differences in average yield of breeds between the districts, but the order of yield between districts is almost the same for each of the 3 breeds. Arranged from highest to lowest according to average yield these 6 meteorological districts read: 3, East of England; 5, SE. England; 4, Midlands; 8, SW. England and S. Wales, 2, NE. England, and 7 NW. England and N. Wales. The only deviation from this order is a reversal of order of districts 4 and 5 for Friesians, whose average yield in district 4 was 8,532 lb. and 8,497 lb. in district 5. The difference in average yield between highest and lowest district was 1,559 lb. of milk for Friesians, 1,431 lb. for Ayrshires, and 1,481 lb. for Shorthorns. These findings are in general accord with those of Edwards [15], who noted that Shorthorn and Friesian yields were affected similarly by districts, and that yields decreased from east to west of England.

The rank in yield of the districts does not, however, appear to be related either to the rank of rainfall or to that of average temperature as shown by the hythergraphs. It is true that the highest-yielding district—

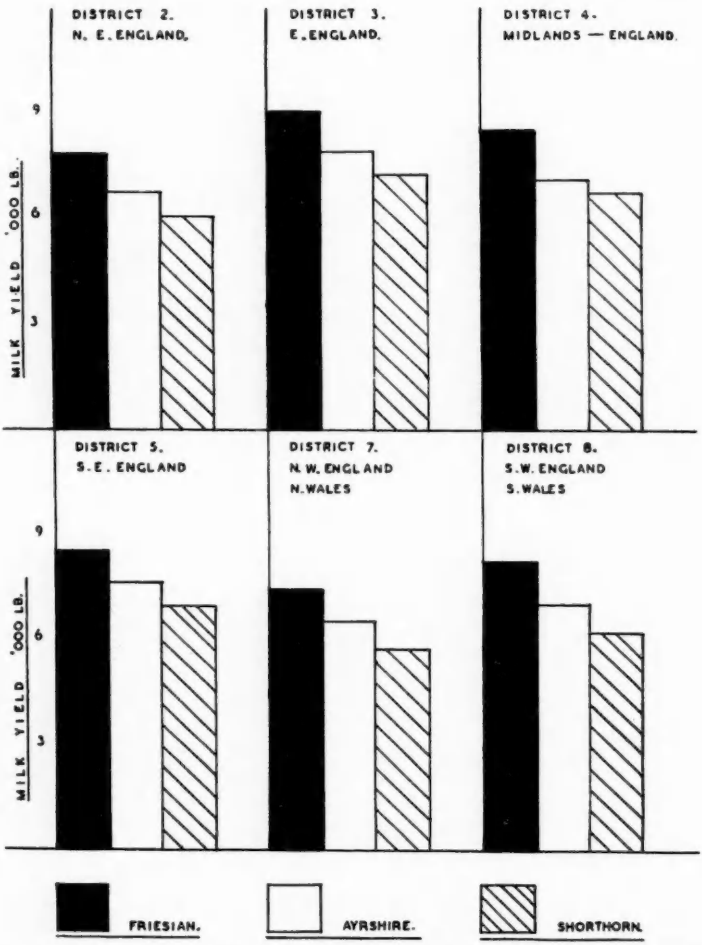

FIG. 2. Average milk yield (lb.) of recorded herds of the Friesian, Ayrshire, and Shorthorn breeds of cattle in 1945–6 in six meteorological districts of England and Wales.

East of England—also has the lowest average monthly rainfall, which may be of advantage; similarly the two districts (Nos. 2 and 7) with lowest average yield have the lowest average monthly temperature in April and May and again in September. This might affect the length of

the grazing season. The amounts in average monthly rainfall and in average temperature which separate the districts are, however, so small that it would be wrong to read any significance into these slight associations between yield and climate.

Discussion

The approach used in this paper to the problem of breed distribution in relation to climate might be criticized on at least three considerations:

1. The pedigree female population may not be representative of the total population for each of the three breeds.
2. The districts used vary in size.
3. The hythergraphs for the present purposes might be irrelevant.

That registered females of each breed may not be representative of the total population of that breed is largely irrelevant here, because in studying the registered populations only, fair comparison is being made between the portions of each breed which will contribute most genetically to the future generations of their respective populations.

The fact that districts vary in size cannot be ignored. On the one hand, the larger the district the greater the chance for internal temperature and rainfall variations, and the less representative is any average figure of conditions in any part of a large area. On the other hand, the districts were chosen by the Meteorological Office in part, no doubt, as climatic entities, not only as geographic ones. Size of district may, of course, of itself influence the proportion of the total pedigree population of any breed that is found in the district, but this should not affect the inter-breed relationship as used here.

The data presented are considered to be only crude approximations, but the conclusion seems warranted that temperature and rainfall in themselves—within the range found in England and Wales—have played little part in determining the numerical relations of the three breeds of cattle—although an indication that rainfall may play some part was indicated by the relationship of increasing rainfall and increasing Shorthorn proportion shown earlier. The Ayrshire breed does not appear to have succeeded best in relation to the other two breeds in districts of England and Wales showing the greatest climatic affinity with its native area—climate, that is, as represented by the hythergraphs.

These mainly negative conclusions are not very surprising if the range of mean monthly temperature and monthly rainfall is considered over a period of time. Thus it can be shown by the procedure described under 'Material and Methods' that the range of monthly mean temperature and monthly rainfall that had obtained over 18 years in the county of Ayr, includes all the extreme points of monthly means as shown in the *Book of Normals* for all the major districts for which hythergraphs were drawn.

It was stated earlier that observed differences in average milk yield between districts cannot, with any confidence, be related to climatic differences as shown by the hythergraphs. Temperature and rainfall, and therefore hythergraphs, are not, of course, the whole of the climatic story of any district. Thus, Lee and Phillips [16] list no less than five

climatic elements each related to animal production: viz. temperature, humidity, air-movement, solar radiation, and altitude. If, however, the meteorological districts could be regarded as environmental 'entities', in a broad sense, the higher or lower yield of a breed according to district might be an adaptive response of the breed to its environment. This could lead to the formation of local breed-types in response to selection by—or because of—the environment, if other conditions relating to the size of the population and the interchange of breeding-stock between districts are met. Within the three breeds of cattle considered in this paper, no differentiation of local types can be postulated because of a large amount of migration within each breed [17, 18].

If it can be assumed that differences in average milk yield that exist between breeds indicate differences in genotype of these breeds in respect of milk yield, then the data presented in Fig. 2 show that there has been no genotype-environment interaction (environment defined here by districts). The three breeds are seen to behave similarly in respect of milk yield according to district.

This absence of interaction is brought out by Table 2, which shows for each district the breed-yield relative to the average yield of recorded herds of that breed in England and Wales as a whole. The average breed-yields (England and Wales) were designated 100 per cent. for each of the three breeds. In the highest-yielding district (No. 3) the recorded Friesians yielded 108·6 per cent. of their national average, Ayrshires 111·6 per cent., and Shorthorns 111·8 per cent. The relative yields of recorded herds in the lowest-yielding district (No. 7) were 89·9, 91·6, and 89·0 per cent. respectively. The table shows that there were differences of about 20 per cent. between the relative yields in highest and lowest district, but that these differences were equally reflected by all three breeds.

TABLE 2. *Relative Milk Yield of Recorded Herds of the Ayrshire, Friesian, and Shorthorn Breeds of Cattle in 1945–6 in six Meteorological Districts of England and Wales* (*yields adapted from M.M.B. data*)

	Ayrshires		*British Friesians*		*Shorthorns*	
Meteorological district	*No. of herds*	*District yield as % of average breed-yield*	*No. of herds*	*District yield as % of average breed-yield*	*No. of herds*	*District yield as % of average breed-yield*
2. England NE. .	222	95·8	353	94·7	550	93·7
3. England E. .	157	111·6	482	108·6	435	111·8
4. England Midlands . .	332	100·0	771	102·6	1,123	104·4
5. England SE. .	207	106·1	260	102·2	934	106·4
7. England NW. and N. Wales	229	91·6	427	89·8	732	89·0
8. England SW. and S. Wales	156	98·7	429	98·9	1,249	96·4
England and Wales total herds and average yield of milk (lb.) .	1,303	7,156	2,722	8,315	5,023	6,505

The fact that these yield-differences cannot be ascribed to either temperature or rainfall variation between districts, or to a combination of the two, as shown by the hythergraphs, indicates that either these factors are of little significance in causing these variations, or the hythergraph method is inefficient when applied, as here, to districts which are large relative to the total area of breed-distribution involved, and when climatic variation between districts is not great.

Summary.—Hythergraphs are used to show temperature and rainfall variation from district to district for the six meteorological districts of England and Wales and for the West of Scotland. Alongside the hythergraphs is shown the proportion in each district of pedigree Ayrshire, Friesian, and Shorthorn cattle. It is shown that the proportion of Shorthorns to the other two breeds increases with increasing average winter rainfall (and average annual rainfall) of the districts, but this cannot be accepted as conclusive evidence that, of the three breeds, Shorthorns are preferred for the wetter climatic conditions. There appear to be no other clear associations between breed distribution and climate. Ayrshires have not succeeded best in relation to the other breeds in districts of England and Wales showing closest similarity in climate with the West of Scotland, where Ayrshires originated.

A weakness of the hythergraph method in this investigation lies in that mean temperature and rainfall data for the 35-year period given in the *Book of Normals* hide variation. The range of means during an 18-year period in the county of Ayr alone includes all the extreme points of monthly means based on the 35-year period for all the major districts of the hythergraphs.

The East–West trend of declining milk yield is shown for the Ayrshire, Friesian, and Shorthorn breeds of cattle according to the six meteorological districts. The rank in yield of the districts does not appear to be related either to rank of rainfall or to that of temperature as shown by the hythergraphs. District affects similarly the milk yield of each of the three breeds; there has thus been no genotype environment interaction (genotype defined here by breed, and environment by district).

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DEGENERATE INBRED LINES OF BROWN LEGHORNS AND THEIR FIRST CROSSES

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ALTHOUGH commercial success appears to have attended the use of inbred lines for crossing, there is still a lack of factual data on the nature of their superiority, and on how far the wastage entailed in producing them offsets the economic gain achieved. Apart from the work of Dunn [1], in most flocks already described inbreeding has been accompanied by conscious selection for vigour or some allied productive trait such as hatchability or egg numbers. Crosses from lines maintained on less practical standards also have their value in providing complementary information and a wider basis for the study and elucidation of heterosis in the fowl. This paper concerns the outcome of a few matings of the latter type which may add to knowledge of the phenomenon from an aspect not often available.

Material.—Among the non-interbreeding lines of the 20-year-old closed flock of Brown Leghorns at the Poultry Research Centre are four which have undergone selection for large egg-size (L), small egg-size (S), dwarf body-size (D), and increased redness in the plumage (R). Productive ability has remained a minor requisite in these lines, and none of the traits mentioned would be expected necessarily to contribute to fitness and vigour except perhaps the first. Further, the annual replacements have often been so small that chance must have played a large part in the general direction of their development with increasing homozygosity. As the lines were initiated at different times, and S and L were both later subjected to the introduction of fresh blood from another line, directly comparable descriptions of their original character cannot be provided, but some indications of the background to their development may be gained from Table 1. One or two points there require clarification: the last three sets of averages are annual ones, and the number of dams and sires is calculated from the totals used, irrespective of the number of years in which an individual left offspring, divided by the number of

TABLE 1. *Data for Parental Lines*

Line	*S*	*D*	*L*	*R*
Line closed	1934	1936	1938	1939
1940 Inbreeding coefficient	59	39	39	37
1950 Inbreeding coefficient	74	54	51	61
1940 Body-weight, gm.	1,441	1,303	1,997	1,431
1940 Egg-weight, gm.	50	53	62	52
1940 egg no. Oct.–March	30	50	30	54
Pullets per year	17	17	21	9
Dams per year	6	5	6·5	3
Sires per year	1·3	1·0	1·3	0·7

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years the line has been in separate existence. Coefficients of inbreeding are estimated by Wright's technique [2]; the high figure for the R line in 1940, the second year of its existence, calls for comment: it arose because an S male, already 50 per cent. inbred, was used in its formation, and then mated to his daughters. That this procedure has been instrumental in retaining a high degree of relationship between R and S lines is indicated by the coefficient of inbreeding computed for their cross progeny, which is close to 40 per cent.; estimates for the other crosses about to be described vary between 8 and 10 per cent., levels which are probably close to the minimum now obtainable within the flock.

The figure for egg production, though determined over the same period of the year as for the crosses, is not comparable with theirs since, during war-time, winter lighting normally used in the laying pens had to be discontinued. It can only be taken as indicating the relative ranking of the lines at this date. Egg-weight is derived from the pullet means of eggs laid in March. The birds were weighed in the same month.

In 1950 reciprocal crosses, and comparable samples of the three small lines, R, S, and D, which now show definite symptoms of degeneration, were obtained by mating up a cockerel from each line with pullets of all three. Eggs from all groups were set in the same incubator, and chicks reared together in battery brooders to 6 weeks of age. When the pullets were housed for laying, the crosses were mixed at random in three pens, but the pure lines were each allotted to separate pens.

A single pen-cross was also made between lines D and L, using an L male; the only L control data for it came from the normal replacements for the line, which were sired by three other males. Chicks in these last two categories went through the same stages but apart from the small line progenies, and were also produced in the second half of their hatching season, which extended from mid-January to the beginning of May. Strictly speaking, therefore, they do not parallel the rest of the material, but at some points are an aid to interpreting the results, and so observations on them have been included alongside the others.

Differences of management and maintenance always make it difficult to get a satisfactory comparison between the performances of experimental birds and commercial stock. In the present case the difficulty is increased because, in anticipation of removal of the Centre to new buildings, large numbers of replacement chicks were raised. Delays in obtaining possession of the new quarters and the vicissitudes of settling in resulted in crowded conditions of rearing and other irregularities of husbandry, which were likely to militate against the progress of the birds, and noticeably affected their juvenile viability. In the following pages the small lines and crosses are compared for a number of traits with the replacement stocks of the same year of the best two lines in the flock (B and I); under ordinary conditions they might be expected to approach most nearly the performance of commercial flocks, but they too were subjected to the abnormal conditions prevailing for the chicks hatched in 1950.

The matings analysed here were in the nature of an exploratory test to see what the lines contained before planning further exploitation of their

peculiarities, and the pens were made up according to the number of pullets of each sort that happened to be available.

Results.—Summarized data on incubation behaviour of the individual lines and crosses, and their viability to 6 weeks, are given in Table 2, and grouped comparisons of the two sets, excluding DL and L, in Table 3. In designating the crosses the letter symbolizing the dam's line is given first. The irregular numbers of eggs set are largely a function of the number of dams used and their rate of production over the hatching period.

TABLE 2. *Incubation and Rearing Records*

	R	*S*	*D*	*RS*	*SR*	*RD*	*DR*	*SD*	*DS*	*DL*	*L*
Eggs set, No. . .	112	236	81	91	258	93	89	298	86	137	305
Infertile, % . .	3	51	10	59	20	56	15	35	50	42	12
Embryonic mortality, % . . .	41	29	36	42	22	37	45	26	19	23	31
Mortality to 6 weeks, % . . .	57	31	40	45	16	17	15	2	14	10	28
Hatched of eggs set, % . . .	57	33	58	24	62	28	47	48	40	44	61
Alive 6 weeks, % eggs set . .	23	21	33	12	50	22	37	45	35	39	42

TABLE 3. *Small Lines and their Crosses*

	Unweighted Mean			*Weighted Mean*	
	Lines	*Crosses*	*C*	*Lines*	*Crosses*
Infertility, %	22	34	14	32	35
Embryo mortality, % . . .	35	32	21	35	28
6 weeks' mortality, % . . .	43	18	15	42	13
Hatched, % eggs set . . .	49	41	68	44	47
Alive 6 weeks, % eggs set . .	26	33	58	24	39

The most noticeable point about infertility is that it is least in three of the pure lines, though the very low figure for R is accompanied by the best fertility in the crosses where the same sire was used (SR and DR). At the other extreme are the groups sired by S males; the first cock used was so nearly sterile that he was replaced in mid-February, but even when his effects were excluded the high infertility shown by S, RS, and DS was reduced only to 42, 34, and 24 per cent. respectively, indicating that he was not atypical but merely reflected the increased infertility which has become characteristic of his line. Only 20 per cent. of the infertility shown by the RD group was accounted for by one sterile dam; two DL dams which produced no offspring were responsible for half the figure shown there. Overall, the lines have shown superiority to the crosses, and as a group are better both on the basis of weighted and unweighted means (see Table 3).

There is no distinct difference between the behaviour of the lines and crosses in respect of embryonic mortality, though the latter are slightly

more viable on the average. Three of the four S-line crosses and DL show improvement over their corresponding mid-parent values, whilst three of the four R-line crosses do not; the reciprocals of R and S behave differently, and D is without apparent ability to alter the mean value imprinted on the group by the other contributing line. RS, as will appear, also rates poorest for all other measurements made upon it.

Heterotic effects, however, become definitely operative in the juvenile stages of life, as evidenced by mortality to 6 weeks of age: with the exception of the group last mentioned, losses were much lower in all the crosses than in the lines.

The last two rows of Tables 2 and 3 show the combined effects of these sources of wastage on the relative proportions of chicks hatched, and alive at 6 weeks, expressed as a percentage of eggs set. Though D and R inbreds rank second and third among small line progenies for total hatchability, the general means for lines and crosses are not widely different; it is the differential mortality in the juvenile stages that has the greatest effect in swinging the difference between the two sets in favour of the crosses.

As a control comparison the unweighted means of the contemporary figures for B and I lines are given in column C of Table 3. There was little difference between the two lines for the traits as considered here, but it may be noted in passing that both infertility and juvenile mortality were higher than was to be expected on their previous records; the latter was double that in five earlier years for which comparable records are available.

Adult birds.—There were too many pullets for the space available so their numbers were reduced by cutting out the earlier hatches, and the whole products of others at intervals over the breeding season; the two largest groups, SR and SD, had to be further diminished by eliminating birds at random within the largest hatches. All the R, S, and D pullets were kept and, supplemented in each case by pullets of another mating, were allotted a separate pen for each line. The pens were wired-off divisions of the same brick poultry-house.

The numbers resulting from these operations are given in Table 4. together with group means for performance up to the end of March, Uniformity in mean age at sexual maturity among the crosses is remarkable; even that for DL falls within the narrow range exhibited by the small line-crosses, though one of its parental lines approximates it much more closely than is the case elsewhere. Further, it cannot be inferred

TABLE 4. *Adult Performance of Inbreds and Incrosses*

	R	*S*	*D*	*RS*	*SR*	*RD*	*DR*	*SD*	*DS*	*DL*	*L*
Pullets kept .	19	38	24	2	26	7	6	16	15	24	41
Sex maturity, days	229	250	227	..	201	196	197	194	199	197	207
Body wt., March, gm. . .	1,160	1,250	1,160	..	1,390	1,290	1,290	1,370	1,410	1,450	1,800
Egg wt., March, gm. . .	44	48	50	..	50	51	51	53	52	56	66
Dead to 31.3. No.	0	12	7	1	0	0	1	0	1	2	4
Eggs, Oct.–Mar. No. . .	49	21	27	..	81	91	79	88	80	69	55

from the results that the extremely late maturity, characteristic of the S line, has had any special effect on the crosses containing it. Apart from R and D, the means of the lines differ significantly from one another; the probability of homogeneity of DL and L is also less than 0·05.

With body-weight and egg-weight the situation is slightly different: whilst the small line-crosses present all show improvement over their respective parent lines, DL yields values intermediate between the two inbreds producing it. The slight advantage that S has over R and D in body-weight, and the advantage in egg-weight shown by D, appear to have been carried over to their crosses; there is, however, no statistical confirmation of this: the grouped lines and crosses differ significantly for both variables, but only the line egg-weights show significant differences among themselves.

As was the previous experience [3*a*], pullet mortality among the crosses was very low; it comprised two cases of coccidiosis, two of comb haemorrhage, and one bird 'cannibalized'. L-line birds were also fairly viable, but both D and S had about 30 per cent. mortality over the period examined. That no R pullets died though they showed low viability in early life may be associated with the fact that they were penned by themselves as pullets; it may be that their particular weakness is expressed as an inability to compete with birds of other lines.

Both the wide range of hatching dates and the marked differences in sexual-maturity ages make it difficult to find a criterion of egg production that is not greatly dependent on their variations, and to measure it on a basis of so many weeks from first egg would impose seasonal effects on the inbreds and crosses at different stages. Since, however, sexual maturity necessarily enters into economic aspects of production the measure adopted for it was from October 1 to March 31. General means computed this way are compared in Table 5 with those for the period November 1 to March 31, and show that although the former favour the crosses their ranking is still the same. The percentages given there are for the number of eggs divided by the number of potential laying days. There is no doubt that the individual crosses show marked superiority over the inbreds in egg numbers, but in view of the difficulties just mentioned no importance can be attached to differences among them except perhaps in the case of DL: when October production was excluded it still held an intermediate position between the other crosses and the lines.

In Table 5 a further comparison is made of the small lines and crosses

TABLE 5. *Winter Egg-Production and Mortality*

	Oct. 1–Mar. 31						*Nov.–Mar.*		*Oct.–Mar.*
	Survivors			*Hen-housed*			*Survivors*		*Mortality*
	Pop.	*eggs*	%	*Pop.*	*eggs*	%	*Eggs*	%	%
Small Lines (R, S, D)	62	31	18	81	25	14	31	22	23·5
Crosses (R, S, D) .	69	83	47	72	80	46	76	53	4·2
Production Line B .	79	76	43	98	65	37	73	51	19·4
Production Line I .	42	81	46	44	78	45	79	55	4·5

with the contemporary pullets of the two most productive lines in the flock which, together with crosses between them, were the subject of an earlier report [3*b*]. Though selection for egg numbers has been the practice in both these groups, there is no evidence that they are superior to the small line-crosses in respect of this variable, but neither do the latter exceed them. The B line, being larger than the others, and selected for a number of economic traits, is the nearest approach to a control line existing in the flock.

Discussion.—It was not until after hatching that evidence of hybrid vigour could be clearly distinguished in the small line-crosses. Although the loss from embryonic mortality was slightly less than in the inbreds, the greater proportion of infertile eggs from cross matings overrides this effect in the percentage of total eggs hatched. Wilson [4], who found the regression of infertility on inbreeding practically zero, has pointed out the difficulty of ascribing infertility to particular genetical or environmental sources. The poor fertility of the S-line birds might arise from weakness of the gametes produced. On the other hand, difficulties of mating may occur due to structural or physiological deficiencies and incompatibilities in the animals themselves, and even size-differences, as between D and L lines, may have contributed to it; such agencies are environmental in so far as the actual formation of the zygote is concerned, yet they stem from the genetic constitution of the parental lines as much as any gametic defect. Moreover, they provide cogent reasons why the degree of fertility in crosses might not show improvement over the parental lines, and might even be deleteriously affected by characteristic phenotypic differences between them. This is a possible source of wastage in crossing inbred lines that has not commanded much attention, though Jull [5] also noted it. It may not, of course, be of frequent or marked occurrence, for lines as diverse as those studied here would probably be rare in practice, but its effects are likely to be more insidious in birds than in larger livestock where sterility of matings would impress the breeder at once. Unpublished data on the crosses between the production lines mentioned earlier show that there fertility of the interline matings was at least as good as in the parental lines.

If the advantage of heterosis lies in the bringing together of unlike alleles in the same zygote, it cannot be expressed until fertilization has taken place. It should therefore have made its first appearance here in embryonic mortality, and some but not all of the crosses show improvement in this respect. The contrast between this result and that for 6 weeks' mortality, where all but the RS group are undoubtedly superior to the inbreds, suggests that other factors besides multiple small gene (polygene) effects are entering into the differences in hatchability of fertile eggs. The few other reports on hatchability in crosses of inbred strains [1, 5, 6], all indicate improved performance. This is not necessarily at variance with present findings, for the lines used here are of long standing, and have had ample opportunity to amass deleterious or lethal genes, whilst the others, excepting the lines of Waters, were of comparatively short development; in the latter case hatchability was a major criterion of selection. Though the average viability of the cross chicks

and of the better embryonic groups exceeds those of their parental types, they do not surpass those of the lines used as controls but rather tend to parallel them.

It may be unwise to place too much emphasis on the poor showing of the RS group, for it may be a chance effect, but it is the more noticeable since its reciprocal ranks uniformly high in Table 2; sex-linked differences between them seem unlikely in view of the behaviour of DS from the same sires, but maternal influences cannot be similarly ruled out, for RD ranks next lowest to RS in general performance. It is also noteworthy that these divergent reciprocals are the product of the lines that are likely to possess the greatest residuum of common genotype.

As regards mature performance, the small line-crosses can be considered superior to their parent inbreds in all the variables examined (sexual maturity, body-weight and egg-weight, viability, and winter egg-production); though there have been no deaths among the R pullets, it was pointed out earlier that their inability to compete with other lines would probably have resulted in some mortality had they not been penned separately. In comparison with the B and I lines the crosses equalled but did not exceed them in egg production, whilst their mortality was as low as in the more viable line.

There is, however, a distinction between the small line-crosses and DL in body-weight and egg-weight behaviour; whilst all the former exceed the present means of their parent lines, the DL group lies between them. This was also found in some earlier crosses made between the production lines B and I [3*b*]; there the intermediacy of body-weight means in the crosses related to comparisons with inbreds of the same year; as the latter decreased in size over an eleven-year period, the crosses fell in step with them, as if genes advantageous to this trait were being lost as inbreeding proceeded. The ranking of SR, RD, and DR groups in relation to their parent-lines' performance in 1940 might be interpreted as the result of a similar trend, but both the reciprocal S and D crosses equalled their mid-parent value for that year. All the inbreds have gradually lost weight in the course of their history, but although the means of L, B, and I lines are still within the range exhibited by individuals of the original flock, those for R, S, and D have fallen below it. In D this has followed direct selection for small body-weight; in S it may have been indirectly selected in so far as it is physiologically associated with egg-weight, but in R it seems to have resulted from the smallness of the isolate since it is unlikely (though not impossible if there is an endocrine basis involved) that there would be a correlation between colour and weight.

The general picture leads to the view that deleterious gene interactions have arisen in the small lines that are to some extent broken up in their crosses, but in the less degenerate lines the differences are still mainly dependent on additive gene action, as was found by Hazel and Lamoreux [7] to be the situation for 22 weeks' weight in a commercial flock.

The small line-crosses are not very much heavier than the parent groups, so that unless they carry some homologous interacting genes the

uninhibited genotype of the latter for body-weight cannot be much greater than is indicated by actual expression. That their crosses are so uniform in behaviour, and that the DL mean comes within 30 gm. of the mean of its contributing lines, supports this idea, but data from an F_2 generation would provide more definite information.

The situation as regards egg-weight appears to be much the same as for body-weight. Sexual maturity might be regarded as a factor interacting with March egg-weight in that the late-maturing inbreds would have less time in which to attain maximum egg-size than the more precocious crosses. Before the matings were made it had also been suspected that egg-weight was perhaps being suppressed by small body-size below true expression of its genetic value in the degenerate lines (a type of interaction of which Lerner [8*a*] has found some indication). If this were true, crossing might free it from the ceiling, but evidence of this has not materialized: the ratio, mean egg weight/mean body-weight, is largest in the D line (0·043) and smallest in SR and DS (0·036 and 0·037). Three cross pullets with a mean over 2 oz. occurred, two full sibs from DS each averaged 59 gm., and one DR 57 gm.; their dams, however, were at the higher extreme of the D-line range for egg-weight though the pullets themselves were not extreme in regard to body-weight. In the DL cross, pullet means ranged from 50·5 to 62 gm., but again there was no obvious parallelism between egg-weight and body-weight beyond that normally expected.

The outcome of these experiments is in general consonant with that of earlier reports [5, 9, 10], though Dunn [1], using unselected inbred lines, got no improvement in egg production. Present findings, however, serve to focus attention on two diverse types of response of production traits to incrossing. (A third, encountered in the earlier crosses [3*b*] and described by Warren [11] in R.I. Reds, is founded on a sex-linked difference in sexual maturity.) Consideration of the behaviour of egg-weight and body-weight suggests that the interline crosses yielding intermediate values result from line differences which take the form of simple segregations of additive-weight genes, such as are theoretically to be expected from the technique of inbreeding, whilst the degenerate lines, which produced improved progeny on intermating, show in addition non-additive effects that do not necessarily depend on genes directly affecting the trait itself.

The problem of why these two aspects of inbreeding should show up more readily in weight- than in egg-numbers may be connected with the relative degree of selection which the respective traits have undergone as suggested by Lerner [8*b*]. It may be that, basically, rate of production rests on a few major genes, or that much of the genetic variability directly affecting egg numbers has already been fixed; in either case lack of flexibility may make it more difficult to accommodate itself to inbreeding changes in other organ systems of the individual. The possibility that a situation of this sort may exist might be deduced from an analysis made of March production in B and I lines and their crosses [12] where it was found that mean net-rate of laying in the crosses only equalled that of the better parent line, and that it was the much lower percentage of them

showing gaps in production that enabled them to outstrip both lines in average performance.

Summary.—Four non-interbreeding lines of Brown Leghorns and their first crosses are described. Three of the lines were small and showed signs of inbreeding decay.

Fertility was better in the inbreds than in the interline matings. Crosses, though variable, showed improved embryonic viability on the average; their mortality to 6 weeks of age was much reduced in comparison with the parental lines.

In adult performance the small line-crosses were superior to the inbreds in sexual maturity, body-weight, and egg-weight, viability, and winter egg-production. In the remaining cross with a larger line, body-weight and egg-weight means had values between those of the contributing lines.

Comparison with two of the best lines in the flock indicated that the crosses equalled, but did not exceed, them in juvenile viability and winter egg production.

The two types of response encountered in the crosses, intermediacy and superiority, are discussed in relation to their origin, and their differing incidence in the traits examined.

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DEVELOPMENT OF THE ZEBU HERD OF BUKEDI CATTLE AT SERERE, UGANDA

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Introduction.—Detailed information on Zebu cattle, especially in East Africa, is very scanty and the purpose of this paper is to put on record what we have learnt at Serere during the past ten years, so that as the work progresses we shall have some standard by which we can measure any future improvement. Although our records apply only to cattle in the Serere herd, we have no reason to believe that these differ in any way from the local cattle, which in Uganda are commonly referred to as of the 'Bukedi type'. The picture that immediately springs to mind when the words 'Bukedi cattle' are mentioned is of a small, stocky, extremely hardy type of animal with short horns and a fairly pronounced hump. Colour means very little, and each and every colour and mixture of colours may be seen. Some Africans, however, do not like the brindle. Although a few animals weighing 1,000 lb. may be seen, the mean maximum live-weight for males does not exceed 800 lb. and for females 600 lb.

Serere Experiment Station was established in 1920 in Serere County in the south-west peninsula of Teso District in the Eastern Province of Uganda, and at an average height of about 3,700 ft. above sea-level. The station is intended to serve the short-grass areas of Uganda, which include practically all the Eastern and Northern Provinces and part of the Western Province. The soil is typical of large parts of the area served, and though rather light, it has a tendency for pan formation when worked in wet weather, and hence is easily eroded.

Although Serere enjoys a relatively high rainfall (1920–48, mean 53·72 in.), it is considered as part of the drier area of Uganda. The early rains are reliable, but the second rains are erratic. Periods of up to 3 or 4 months with negligible rainfall between October and February are by no means uncommon. During the dry season, hot weather, usually accompanied by hot winds, prevails and the monthly maxima in January frequently exceed 95° F. and humidity is correspondingly low [1].

The predominant grasses on rough permanent pasture are *Imperata cylindrica*, *Hyparrhenia rufa*, *Sporobolus pyramidalis*, and *Cynodon plectostachyum* on the better soils, whereas the poorer parts still contain much *Rhynchelytrum repens* and *Paspalum commersonii* [1]. The present policy of sowing down with *Chloris gayana* is meeting with increasing success, but, even so, the predominant grass of all ley grazing is *Cynodon plectostachyum*, which gives very good grazing in the first and second years, but in the third year is usually invaded by less palatable grasses, mainly *I. cylindrica* and *S. pyramidalis*. Wherever land in good heart is heavily grazed, *Cynodon* comes in as a bottom grass, and where the nitrate-nitrogen status is high, for example, round cattle kraals, it may be found in almost pure stand.

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Cattle in the Teso District.—The most recent census figures show that in Teso District, which is the largest stock-producing area in the Protectorate, there are approximately 630,000 cattle, equivalent to 146 per square mile; in Soroti County the corresponding cattle density is 198. About 912,000 acres were under cultivation in 1948, which is about one-third of the area of the district, thus leaving slightly less than three acres per head of cattle of resting ley, permanent pasture, and grazeable swamp. Despite this heavy stocking density, there is no overstocking under existing methods of pasture control, except in comparatively small areas. The resting ley is extensively grazed and it is believed that this is largely responsible for the maintenance and possible increase in fertility seen during the past decade [2].

The foundation stock at Serere.—The foundation cows consisted of 57 head purchased between Dec. 1939 and March 1940. Of these, 20 were heifers and cows bought from the old Veterinary Stock Farm at Sukulu near Tororo and the remainder were purchased locally. Apart from 6 heifers purchased in North Teso in September 1941 and 1 heifer purchased locally at Serere in June 1944, no stock has been bought into the herd. As the heifer purchased in 1944 was culled as a poor producer, the herd can be regarded as 'closed' as from 1941.

Ten bulls have been used since the herd was founded, but of these only two need be considered here. A bull, Badcock (L6), was purchased in June 1939 from Ajeluk when about 18 months old. He began serving immediately and, except for the period Feb. 1944 to Sept. 1946, when he was replaced by his son Oula (L71), he continued to serve one or other of the herds until Nov. 1948, and sired 129 calves. Although on the small side, he was of good conformation of the beef-type. Badcock and his son Oula have formed the second line at Serere and between them have sired 197 calves to date.

What has come to be known as the 'first line' at Serere was founded by Katerega (L69), who was born in Feb. 1939, when his dam Ibate (No. 39) was on her way to Serere from Sukulu. She is recorded as being the best milker in the Sukulu herd, although no figures are available. Although Katerega turned out to be of poor conformation from a beef point of view, he was of good size and his progeny test has fully justified his selection. He began serving in Feb. 1941, and except for 3 months in 1947 he continued as the premier herd bull until Jan. 1949, when he was disposed of. He sired 189 calves.

Breeding policy.—The policy for the milking herds has been to line-breed on Katerega, who has been progeny-tested for milk yield and found to be superior to both Badcock and his son Oula. Oula now serves only the Free Range herd. Some bulls sired by Oula are being kept in case they will be required later for improvement of conformation, and he continues to be progeny-tested for both beef and milk by bringing his heifers into the breeding herds. Three sons of Katerega (Kyobe (R10), Stephens (L7), and Williams (R37)), all out of the same dam Akwazo (No. 64)), are now being used in the milk herds, and out of 583 calves born to the end of July 1950, Katerega and his sons have sired 326.

TABLE 1. *The Genealogy of the Katerega*

Ibate (No. 34) Sukulu × Achiragete (R27) Sukulu

Amoding (No. 56) × Katerega L69 × Akwazo (No. 64) Usuku
(Feb. 6, 1939)

Okope (L19)	Otuba (R45)	Kyobe (R10)	Stephens (L7)	Williams (R37)
b. July '44	b. July '46	b. Jan. '44	b. July '45	b. Oct. '46
(Ngetta)	(Entebbe)	(Serere)	(Serere)	(Serere)

The primary aim at Serere is to provide improved breeding stock for Teso District, which is essentially a beef-producing area. Early experience, both at Serere and in the field, showed that many cows do not have sufficient milk to feed their calves adequately, let alone give any surplus for human consumption. Also, the weight records at Serere have very clearly indicated that one of the reasons for the slow rate of maturity of the local Zebu cattle is the relatively poor live-weight gains from birth to weaning. Our policy, therefore, has been to select for milk yield, so as to ensure that the calf gets a good start in life, and not to breed-up a purely dairy-type of animal—that will come later if the demand requires it. At no time has the question of conformation for beef-production and stamina for work been neglected. The results so far obtained at Serere have shown that the production of a dual-purpose type of animal for both beef and milk, with the emphasis on the beef, is a real practical possibility.

Visitors to Serere, especially those from the U.K. or U.S.A., frequently ask whether we have tried top-crossing our selected local cattle with imported European breeds. Our answer is that nowhere in Uganda have such crosses proved successful owing largely to low nutritive conditions and to a reduced resistance to endemic diseases; and that our present policy is to try and make the best of the local indigenous type of cattle. So far we have not been disappointed.

Results

Serere is primarily a plant-breeding-cum-field-experiment station, and the work done on animal husbandry during the past decade has been very largely of secondary importance. Our purpose has been to try and devise the best farming system for local conditions in which the keeping of stock must form an integral part. In all our field experiments and field trials, the ultimate yardstick by which all treatments are judged is the effect of those treatments on the fertility of the soil as measured by crop yields when the land is eventually opened up to cropping. At the same time, by selective breeding and improved stock management we have tried to improve the cattle on the station and to learn something about them.

Live-weight Gains

(*a*) *Maturity*.—One of the first things we set out to determine at Serere is how long the local type of Zebu takes to reach maturity, and for

this purpose all cattle, since Jan. 1943, have been weighed at birth and at monthly intervals thereafter.

Figure 1 shows the live-weight gains for males and females at 6-monthly intervals; it indicates that females reach maturity at approximately 42 months, but males do not reach maximum weight until about 66 months of age. At no point in the graph does the female weigh more than the male.

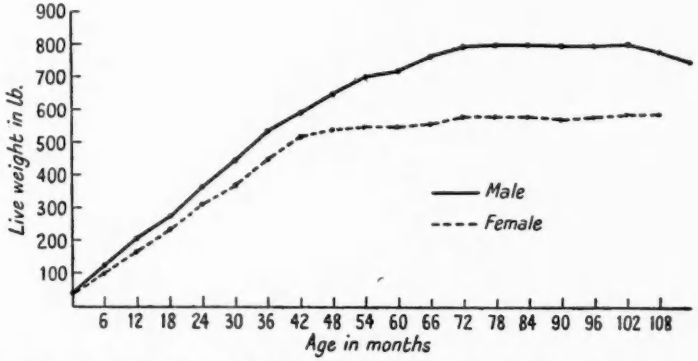

FIG. 1. Showing live-weight gains in the Serere Zebu herd at various ages.

Table 2 has been compiled from the mean weights of 388 animals born between Jan. 1, 1942 and Dec. 31, 1949, of which 191 were male and 197 were female.

TABLE 2. *Live-weights of Male and Female Calves*

Age in months	*Live-weight in lb.*	
	Male	*Female*
Birth	40	35
6	124	114
12	205	173
24	362	314
36	530	453
48	647	537
60	716	555
72	795	580
84	805	576

The age of maturity for the females corresponds almost exactly with the age of calving down (42 months, see p. 148). The males make uniform gains up to about 42 months, at which point the graph falls away rapidly. This period of diminishing live-weight increase corresponds almost exactly with the age at which the animals begin to be trained for work, although we seldom work them steadily under 48 months. From birth to 42 months the graph is almost a straight line, which, if continued, would give a 1,000 lb. beast at about 80 months. At Serere we have

several animals in the working herd which exceed 1,000 lb., but they are the exception rather than the rule. The heaviest beast so far recorded is Echaku (R20), a working ox which weighed 1,068 lb. at 10 years of age, and first passed the 1,000 lb. mark at 7 years.

(*b*) East Coast Fever (*Theileriasis*) is endemic in many parts of Teso District and it is therefore essential that all cattle on the station, and more especially those intended for sale or transfer, should have acquired immunity to this disease. The two prevalent tick species in Teso District infecting cattle are *Rhipicephalus appendiculatus* and *Amblyomma variegatum*, the former being the chief vector of East Coast fever. Dipping of cattle in Serere started in 1940 and the policy since then has been to dip all animals at weekly intervals, except calves, which are not dipped until they have been weaned.

In Dec. 1948 investigations were started to get laboratory proof of the incidence of East Coast fever. That the incidence is not so heavy as was previously thought is shown by the fact that out of 81 calves born since the investigations began only 49 showed typical clinical symptoms of the disease, and of these only 17 had positive blood slides. The infected animal loses condition for about 10–14 days, but no corresponding loss in weight is evident from the graph, and the probable explanation is that the incidence of the disease is spread fairly uniformly over the first year of life.

(*c*) *Maximum and minimum birth-weights of calves.*

Heaviest male: the fifth calf out of cow No. 61 Apiyo II by Kyobe. Weight at birth 57 lb.

Heaviest female: the ninth calf out of cow No. 56 Amoding by Katerega. Weight at birth 61 lb.

Lightest male: the first calf out of cow No. 76 Imucheri by Katerega. Weight at birth 24 lb.

Lightest female: the second calf out of cow No. 76 Imucheri by Badcock. Weight at birth 21 lb.

Note 1. Apiyo II (No. 61) the dam of the heaviest bull calf is herself a daughter of Amoding (No. 56) by Badcock, who in turn is the mother of the heaviest heifer calf.

Note 2. Both the lightest male and lightest female calf were out of the same cow, but by different sires. Neither is recorded as being premature in any way and both have survived. The birth-weight of Imucheri No. 76 is not recorded, but she weighed only 43 lb. at 1 month.

Note 3. There is no noticeable seasonal influence on birth-weight.

(*d*) *Effect of advancing lactations on the birth-weight of calves.*—Table 3 was compiled from the records of 320 calves born between 1940 and 1950. In each case the calf was weighed within a few hours of birth.

From the records it appears that the birth-weight increases up to the third calf born, and then there is no material change until the tenth calf, when there is a marked drop in weight, unless influenced by some other factor, such as a short interval between calvings or a heavier bull being used in the herd.

TABLE 3. *Effect of Advancing Lactation on the Birth-weight of Calves*

No. of calves	*Lactation*	*Mean weight at birth (lb.)*
60	1st	34·7
50	2nd	37·4
44	3rd	39·9
36	4th	39·3
36	5th	40·6
34	6th	39·2
27	7th	40·0
24	8th	40·5
16	9th	41·8
10	10th	36·5
4	11th	34·8

Production Statistics

A. *Productive Cows*

(*a*) A total of 154 cows have been milked to date on the Station since the herd was started in 1939.

(*b*) Only one beast is recorded as being barren.

(*c*) The number of effective calvings from 154 cows recorded in the period under review is 570 or 3·70 per cow. 'Effective calvings' connotes the gross number of calves divided by the number of cows which have calved, i.e. it includes young cows as well as those which have completed their productive life.

(*d*) The total number of recorded abortions is 18; thus the percentage of effective calvings has been 96·8 per cent. In May 1940 26 cows and heifers were tested for contagious abortion and of these 5 were found to be positive reactors and were culled from the herd.

B. *Intervals Between Calvings*

TABLE 4. *Intervals between Calvings* (*Grouped according to Lactation*)

No. of cows	*Lactation*	*Mean interval (days)*
117	1st–2nd	399
90	2nd–3rd	384
64	3rd–4th	356
51	4th–5th	373
38	5th–6th	350
34	6th–7th	349
25	7th–8th	369
16	8th–9th	361
11	9th–10th	360
4	10th–11th	363
1	11th–12th	323
1	12th–13th	434
Total and means 452	All	368

Table 4 has been compiled from information based on 452 calvings, all of which occurred on the Station. There was one period between Dec. 1939 and June 1940 when no bull ran with the herd, thus accounting for the few calves born in 1940–1, and also for some of the very long intervals between calvings as recorded. Again, there was a period early in 1941 when controlled mating was tried out, but this does not appear to have been effective, and in some cases the interval between calvings was greatly increased.

The age of the cow does not appear to affect the interval, and the problem at Serere with Zebu cows, whose oestrus period is extremely brief, has been one of trying to adjust the interval to one nearer 365 days. Since Jan. 1949 it has been the policy for all cows, as they calved, to be placed in an empty herd, i.e. without a bull, and kept there for about 8 weeks and then put in a herd with a bull. So far, the scheme has generally proved successful, although there have been two cases of difficulty in getting the cows in calf again. In neither case, however, was this due to the cow refusing to take the bull, as they were both served at least four times over a period of months before they were eventually in calf.

TABLE 5. *Variation in Calving Intervals by Periods*

Calving interval, days	*No. of cows*
Under 300	11
Between 301–350	201
351–400	135
401–450	49
451–500	21
Over 500	35
Total no. of cows	452

The standard lactation period of 305 days has been adopted at Serere, although, at present, few cows reach this figure. Allowing a 60-day rest-period, the ideal interval between calving would be 365 days. From Table 5 it will be seen that 47 per cent. have calved with too short an interval, 30 per cent. with a more or less normal and 23 per cent. with too long an interval.

C. *Age of Heifer at First Calving Down*

Of 76 heifers which have calved-down on the Station, the age at first-calving has varied from as low as 25 months to as high as 52 months, the mean being 41 months. During the past 2 years under review the mean has been 42 months and, under present conditions, this would appear to be the most satisfactory for the type of cattle reared at Serere (see p. 145). At Serere the heifers are not put into one of the breeding herds until they reach 450 lb. live-weight, which, on average, they reach at 32 months, so that it is clear that they take the bull almost immediately.

D. *Effective Life of a Cow*

Judging by some of the original cows which have already completed at least 8 lactations, it would appear that with good management the Serere type of animal can complete at least 10 profitable lactations. Ten of these cows have produced their highest yields in the lactations as shown in Table 6.

TABLE 6. *Cows that have Completed at least 8 Lactations, Showing the Lactation in which they made their Highest Yield*

No.	*Name*	*Lactation*	*Yield (gals.)*	*No. of days*
6	Lebeka	10th	255	305
7	Lakyeri	10th	308	305
10	Sesiria	8th	228	305
12	Naitono	9th	214	261
24	Abawo	10th	137	301
32	Abezo	9th	157	269
35	Atara	9th	116	289
37	Abeja	10th	127	284
56	Amoding	10th	159	201
69	Amani	9th	215	242

Note 1. All the above cows were milked with calf-at-foot, i.e. they suckled their calves.

Note 2. The inference from this table that cows give their maximum milk yield in their 8th, 9th, or 10th lactations is unsound. Management has been improved and the proportion of milk taken by calves has been reduced. This table is inserted only to show that many cows have long productive lives.

Calf Statistics

(*a*) *Sex ratio.* The total number of live calves born on the Station during the 10 years under review was 583; of these 282 (48 per cent.) were heifer calves, and 301 (52 per cent.) were bull calves.

(*b*) *Twin calves.* Not a single case of twins has been recorded at Serere, but the bull Oula (L71), while on loan to Ngetta Experiment Station, threw identical twin bull-calves, which bore a strong resemblance to their sire.

(*c*) *Calf mortality.* Of the 583 live calves born at Serere, 479 (82 per cent.) were reared beyond the weaning stage, and 104 (18 per cent.) died before weaning. Table 7 shows the causes of death.

Of the 104 calves which died, 39 (37·5 per cent.) were heifers and 65 (62·5 per cent.) were bull calves.

In the early years, deaths recorded as being due to East Coast fever were high and averaged over 30 per cent. In Jan. 1944 11 out of 13 deaths were due to this disease. Starting from February in that year, all calves showing signs of East Coast fever were treated with M and B 693 (Sulphapyridine), since when, during the remaining 11 months of the

year, only 1 calf died from the disease, and during the last 5 years deaths from this disease have been almost negligible. Though this drug has been shown to have no effects on the protozoa causing East Coast fever, many calves so infected undoubtedly die of pneumonia, and the drug presumably has prevented this secondary infection (*cf.* p. 146).

TABLE 7. *Causes of Death before Weaning 1940–50*

Causes	*Calves*
East Coast fever or complications following	52
East Coast fever (not definitely recorded)	24
Premature or weak at birth	5
White scour	7
Injuries—mechanical	2
Enteritis	2
Hoven	4
Black quarter	1
Pneumonia	1
Mother died, would not feed from bucket or bottle	1
Taken by leopard, snakes, &c.	4
Paralysis	1
Total	104

TABLE 8. *Age Incidence of Mortality in Calves 1940–50*

Age in months	*Male mortality*	*Female mortality*	*Total mortality*
Under 1	9	8	17
1–2	6	3	9
2–3	6	8	14
3–4	12	5	17
4–5	12	8	20
5–6	6	5	11
6–7	2	2	4
7–8	1	1	2
8–9	1	2	3
9–10	5	2	7
Totals	60	44	104

Milk Yields

As explained under breeding policy above, we have at Serere, during the past 10 years, been selecting for milk yield so as to ensure that the dam has at least sufficient milk to rear her calf successfully. Comparison of milk yields from year to year is somewhat difficult to assess as full records were not kept until 1945, and up to and including 1944 only once-a-day milking was practised, the calves being allowed to take the evening's milk.

At the present time there are 52 cows and heifers in the milking herds which have completed one or more lactations. Of these, 6 have given yields of over 300 gals. in a lactation, and a further 27 have given over

200 gals. Of the 6 which have given over 300 gals., 4 were milked-out, and the remaining 2 were milked with calf-at-foot. Of the 4 milked-out, 2 were first-calving heifers.

TABLE 9. *Showing Mean Lactation Yields by Years*

Year	*No. of cows*	*Milk yield (lb.)*	*No. of days*	*Milk yield per day (lb.)*
1942–3	5	906	300	3·02
1943–4	21	793	267	2·97
1944–5	31	1,057	263	4·03
1945–6	35	1,244	254	4·90
1946–7	40	1,158	233	4·97
1947–8	42	1,577	244	4·46
1948–9	52	1,595	237	6·73
1949–50	34	2,003	282	7·10

In Table 9 only cows which were milked for a period exceeding 100 days have been included. Up to and including 1944 only once-a-day milking was practised, and the procedure was to milk-out on the 15th day of each month and to base the monthly milk yield on that figure. The training of heifers to milk-out was started in the 1945–6 season. At first, results were disappointing, but to date 42 heifers out of 50 (84 per cent.) have been trained to milk-out without calf-at-foot and this is now normal practice. Failures are now very rare. Table 10 shows the mean yield per completed lactation of cows with calf-at-foot for the different years, and Table 11 of those milked-out.

TABLE 10. *Average Milk Yield with Calves-at-foot*

Season	*No. of cows*	*Milk yield (lb.)*	*No. of days*	*Milk yield per day (lb.)*
1942–3	5	906	300	3·02
1943–4	21	793	267	2·97
1944–5	31	1,057	263	4·02
1945–6	34	1,265	256	4·94
1946–7	34	1,063	233	4·56
1947–8	33	1,625	242	6·71
1948–9	31	1,663	233	7·15
1949–50	17	1,934	277	7·00

TABLE 11. *Average Milk Yields (Cows and Heifers Milked-out) 1945–50*

Season	*No. of cows*	*Milk yield (lb.)*	*No. of days*	*Milk yield per day (lb.)*
1945–6	1	937	185	5·06
1946–7	6	1,527	232	6·58
1947–8	9	1,399	251	5·57
1948–9	21	1,493	245	6·10
1949–50	17	2,072	287	7·23

As we are progeny-testing our bulls, all heifers are brought into the milk herds so that the milked-out herd includes a very high proportion of first-calving heifers. On the other hand, the cows milked with calf-at-foot consist mostly of the older cows, which, as a result of rigorous culling, are almost entirely the high-yielding animals. This would account for the small difference in average yield at present between those milked-out and those with calf-at-foot.

Fig. 2 shows how the mean daily yield for all cows has been improved during the past 7 years.

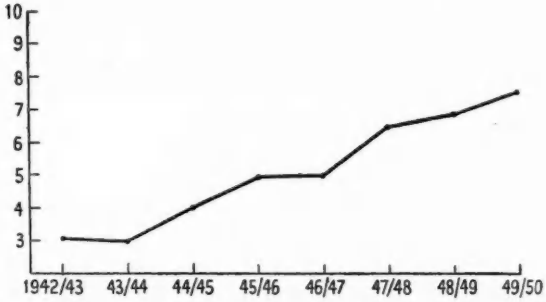

FIG. 2. Mean yield in lb. per cow per day for the whole herd.

Individual milk yields.—The highest yield so far recorded has been by a milked-out heifer No. 124, Ajolo, born at Serere in Nov. 1945, by Katerega (L69) out of Naitono (No. 12), one of the foundation cows purchased from the Sukulu Stock Farm. Naitono has an excellent record for consistent high milk-production, her highest being 214 gals. in her 9th lactation. The best of the cows milked with calf-at-foot is No. 64, Akwazo II. Her breeding is unknown, as she was purchased. Her record is as follows (in addition to feeding her calf).

TABLE 12. *Lifetime Record of Best Cow in Herd*

Lactation	*Milk yield (lb.)*	*No. of days*
1st	1,165	300
2nd	1,964	300
3rd	2,347	270
4th	2,585	300
5th	2,810	300
6th	2,791	305
7th	3,590	305

She is a good-sized cow of good conformation and is the dam of all three bulls, Kyobe, Stephens, and Williams, now used in the breeding herds at Serere. In each case she was mated with Katerega (L69). So

far, she has given birth to 4 heifer calves, but of these only 1, her first calf, has come into milk and she was culled as a poor producer. It is particularly encouraging that 3 of the best of the foundation cows—Naitono (No. 12), Labeka (No. 6), and Labyeri (No. 7)—when mated with Katerega (L69) have each produced a 300-gallon daughter.

Butter-fat testing.—Although milk recording was started in 1942, butter-fat testing did not begin until Aug. 1949. The test is now made in the middle of each month from all cows, so that the test goes back for 15 days and on for 15 days in the same way as the official method of testing overseas. The means of all tests carried out so far have been: cows milked-out without calf-at-foot, 5·8 per cent.; cows with calf-at-foot, 5·5 per cent.

If we take a mean fat-content for all cows milked at Serere at 5·6 per cent., the butter-fat production for the 1949–50 season works out at 112 lb. of fat per cow.

Calf management.—Cumulative gains are recorded for groups of cattle and calves at all livestock stations in Uganda. The average gain per day for each group is recorded each month. The 'year' for all records is from April 1 to March 31. Monthly mean gains are added together to form an annual cumulative gain. In the case of young stock, animals are regularly brought in and regularly promoted to a higher age group. The 'cumulative gain', therefore, represents the cumulative gain of a group of approximately similar constitution at all times, but not of the same individuals. This figure also tends to eliminate the effect of monthly fluctuations. Fig. 3 shows the cumulative gain, in the 1949–50 season, of calves reared on three systems, and Table 13 the gains for three seasons.

TABLE 13. *Cumulative gains of Calves for Different Methods of Feeding* (*Mean annual gain per calf in lb.*)

Method of feeding	*1947–8* (*lb.*)	*1948–9* (*lb.*)	*1949–50* (*lb.*)
(*a*) Bucket-fed. . . .	206	199	218
(*b*) Calf-at-foot . . .	130	162	208
(*c*) Free range . . .	307	305	379

(*a*) Bucket-fed means that the calves are taken away immediately after birth and are hand-reared. Such calves are usually weaned at approximately 6 months.

(*b*) Calf-at-foot means that the calf is allowed to suckle morning and evening just before the mother is milked.

(*c*) Calf on free range. The calf can suckle *ad lib.* as the mother is never milked.

The fact that the superior live-weight gains of the free-range calves after weaning is not maintained is shown in Table 14, but, even so, the superiority of free-ranging for beef production is very great, especially

when we remember that the free-range herd consists only of poor milkers. Experience at Serere is that many of our cows will not let down their milk to human hands, i.e. the problem is more psychological than physiological.

TABLE 14. *Effect of Method of Rearing on Weights of Cattle at Different Ages*

Method of feeding	*No. of animals*	*Wt. at weaning*	*Wt. at 1 yr.*	*Wt. at 2 yrs.*	*Increase 1–2 yrs.* %	*Wt. at 3 yrs.*	*Increase 2–3 yrs.* %
(*a*) Bucket-fed	12	161	177	344	94	489	42
(*b*) Calf-at-foot	30	170	188	353	86	521	48
(*c*) Free range	6	238	281	419	49	582	39

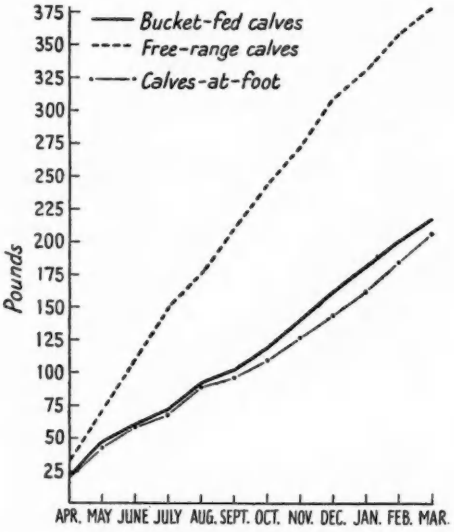

FIG. 3. Cumulative live-weight gains of calves reared on three systems. Season 1949–50.

Highly significant is the fact that calves reared on free range for the first 7 months of their lives weigh nearly 100 lb. more at 3 years than those which are bucket-fed, and 60 lb. more than those which suckle their dams in the milking herds, and more especially because all cows in the free range were classed as 'poor milkers'. Trials are now being started to test the effect on calf live-weight gains of more frequent bucket-feeding—up to 6 times in a day; the suggestion being that perhaps the digestive system of our Zebu cattle necessitates the milk being taken in small amounts at frequent intervals.

Carcass Percentages and Wastage

Slaughter records are available for 32 cows and 93 oxen and the results are summarized below. In each case the live-weight was taken immediately before slaughter and the animals were given no food on the day when they were slaughtered.

TABLE 15. *Carcass Percentages by Age-Groups of Cows and Heifers*

Years of age	*No. of cows*	*Av. live-weight (lb.)*	*Av. dressed carcass-weight (lb.)*	*Carcass percentage*
4	2	487	229	47·2
5	8	597	263	45·1
6	10	645	320	49·5
7	5	576	289	50·2
8	2	576	298	51·7
9	2	626	322	51·1
10	3	555	236	42·1

TABLE 16. *Carcass Percentages of Oxen*

Years of age	*No. of oxen*	*Av. live-weight (lb.)*	*Av. dressed carcass-weight (lb.)*	*Carcass percentage*
4	7	763	373	48·9
5	12	674	343	50·8
6	10	770	405	52·6
7	5	749	397	52·7
8	2	757	388	51·3
9	5	845	422	49·9
10	6	808	389	48·1
11	9	695	327	47·0
12	13	709	326	46·0
13	9	712	327	45·9
14	7	704	336	45·7
15	3	709	332	46·9
16	3	733	358	48·8
17	2	642	282	44·0

For beef cattle the optimum age at which to slaughter is probably now about 6 years. Experience at Serere has shown that from 5 years onwards the quality of the meat tends to deteriorate, although the meat from a 17-year-old beast is still popular with Africans, and with the present regulations sells for the same price as 'baby' beef.

Out of 234 head of cattle of both sexes slaughtered at Serere over the past 9 years only 9 carcasses have been condemned as being unfit for human consumption. Of these 9 the reason for condemnation is not recorded in 6 cases, but the majority of these were probably on account of 'measles' (*Cysticercus bovis*). The remaining 3 cases were due to uraemia, emaciation, and pleurisy, respectively. There is not a single recorded case of an animal being condemned for tuberculosis.

Progeny Testing

All bulls used in the herds are progeny-tested for prepotency for milk and for live-weight gains. As it takes about 8 years from the birth of the bull to the completion of the first lactation of his heifers, our records are still somewhat scanty, and so far are available for only 3 bulls. The results are summarized in Table 18. In calculating the mean yields, all cows and heifers by a bull have been included whether or not they were subsequently culled. An index derived from the increased yields of the daughters over their dams was not considered to be practicable owing to the improvement in management technique over the last 7 years.

TABLE 17. *Numbers of Progeny of Different Bulls Milked-out or Milked with Calf-at-foot*

Bull	*Milked-out*	*Milked with calf-at-foot*	*Total*
Katerega . . .	25	8	33
Badcock . . .	5	8	13
Oula . . .	9	0	9

All cows at Serere are milked twice daily and in calculating the records in Table 18 no adjustment has been made for those cows milked with calf-at-foot, as the numbers were proportionately few except in the case of Badcock (see Table 17). Test weighing to determine the amount of milk taken by the calf is now in progress, but no figures are yet available, and no useful purpose would be served by taking an arbitrary figure.

It will be seen that Katerega has sired higher-yielding daughters than Badcock in nearly every lactation, and that his overall culling-rate is considerably lower. Oula's progeny have been disappointing in their first lactation but may compare more favourably in later lactations.

Weight records.—Table 19 shows the mean weights of the male progeny of the above three bulls at different ages.

Animal Management

Perhaps the most important lesson learnt at Serere during the past decade has been that the local type of Zebu animal will respond to good care and management, and that even the smallest effort is well worth while. This does not mean that we recommend that all cattle should be housed and milked in covered sheds, because at Serere only the three milking herds and the best of the working oxen are kraaled at night and this is primarily to get the manure. What is more important is that the animals should be adequately fed and watered every day. The main problem under Serere conditions is to keep the animals in good condition during the dry season each year, which may last up to 5 months. It is pitiful to see the way the local cattle in Teso lose condition in the dry season through the complete failure of their owners to make some provision for supplementary feeding while it lasts. Undoubtedly this low plane of nutrition accounts very largely for the slow rate of maturity, as

TABLE 18. *Progeny Test of Herd Bulls up to August 1950*

Lactation		*Katerega*	*Badcock*	*Oula*
First	Mean yield (lb.)	1,595	799	844
	Days in lactation	216	216	139
	Cows milked or tried	33	13	9
	Cows subsequently culled	8	3	4
	Percentage culled	24	33	44
Second	Mean yield (lb.)	1,480	1,242	
	Days in lactation	271	252	
	Cows milked	17	10	..
	Cows subsequently culled	0	1	
	Percentage culled	0	10	
Third	Mean yield (lb.)	2,085	1,275	
	Days in lactation	257	220	
	Cows milked	11	8	..
	Cows subsequently culled	1	1	
	Percentage culled	9	11	
Fourth	Mean yield (lb.)	1,356	1,507	
	Days in lactation	225	251	
	Cows milked	4	7	..
	Cows subsequently culled	1	0	
	Percentage culled	25	0	
Fifth	Mean yield (lb.)	2,338	1,949	
	Days in lactation	304	245	
	Cows milked	2	6	..
	Cows subsequently culled	0	1	
	Percentage culled	0	17	
Mean of best lactation of all cows		1,829	1,373	844
Overall culling percentage		30	46	44

TABLE 19. *Weights of Progeny (male) of Bulls used in Herd*

Name of bull	*Weights (lb.)*				
	At birth	*1 year*	*2 years*	*3 years*	*4 years*
Katerega	41·2	201·2	375·4	550·8	703·5
Oula	40·3	202·4	378·2	550·0	735·0
Badcock	42·8	203·3	343·1	497·9	618·6

in most years the animals have barely recovered from the previous dry season when they are once again faced by a food shortage.

Experience at Serere has shown that for young stock kept outside all the year round, good management of the pastures, especially making use of short leys, will see us through a normal dry season of 3 months without supplementary feeding, but any extension of the dry weather beyond this period necessitates some form of supplementary feeding. Working cattle on the other hand require some additional concentrated food in the dry weather to maintain them in good condition; and cows in milk need to have their basic ration increased to compensate for the shortage of grass.

At Serere all the supplementary foods used are home grown, and the basic constituents are sorghum silage and cotton seed. In addition, all adult stock have access to rock salt. For many years all cows and working cattle have received a basic ration of 3 lb. of cotton seed and approximately 12 lb. of silage when good grass is scarce.

Lacking the facilities for carrying out digestibility trials, feeding has had to be largely empirical; it has been based on European standards after making due allowance for the difference in size of the animal and the much higher fat-content of the milk. This work is still in its infancy, and has been largely directed to finding out what local foodstuffs can be used and what can be done to increase the milk yield. In the early stages when the heifers were being trained to milk-out they were given, when available, a few cooked sweet potatoes to keep them contented; this was in addition to the 3 lb. of cotton seed allowed per day. It was noticed that this small amount of readily digested carbohydrate food tended to increase the milk yield and was attributed to the psychological effect on the animal. At the same time empirical observations over a number of years have failed to show that the feeding of cotton seed (17 per cent. of digestible protein) has had any appreciable effect on milk yield, although it undoubtedly helps to keep the animals in good condition. At no time did the animals show any great enthusiasm for whole cotton seed even when fed with salt, and it was very seldom that the troughs were cleaned up.

In Sept. 1947 all the milked-out cows and heifers were given increased amounts of boiled sweet potatoes until eventually the following standard ration per gallon of milk was evolved, it being presupposed that under local conditions the average cow gets at least its maintenance ration from the grass it eats while out grazing: 10 lb. of cooked sweet potatoes and $3\frac{1}{2}$ lb. of cotton seed and some salt.

Reference to Morrison's Tables [3] will show that this ration is just about right for protein (0·6 lb.), but is about double the normal ration for starch equivalent (5·5 lb.) per gallon of milk. Before feeding this ration the daily milk yield averaged approximately 5 lb. per cow, and although it is impossible to say what proportion of the improvement in milk yield has been due to better feeding and how much to selection, the fact remains that since feeding this supplementary ration, in which emphasis is laid on the amount of digestible carbohydrate, the mean daily yield has increased fairly steadily to 7·5 lb. per cow in the year ended March 31, 1950, and is still rising (see Fig. 2). Rendel and Robertson [4] have shown that the maximum genetic improvement in milk yield in a closed herd of dairy cattle is of the order of 1 per cent. of the average annual yield, and there is no reason to believe that this figure does not apply to a closed herd of Zebu cattle. We are left therefore with the conclusion that the improvement in milk yield of the Serere herd during the last 3 years is almost entirely due to better feeding and management, which completely supports the personal observations of the authors. It is this fact above all others that is so encouraging, because the same means are open to all African cattle-owners who have the will to try. At Serere we have done nothing that cannot be carried out by any enterprising African farmer.

As sweet potatoes are not available throughout the year it was necessary to have alternative but equivalent rations. Experience has shown that fresh sweet potatoes can be replaced by an equivalent amount of sweet-potato flour (made by sun-drying and grinding in a hammer-mill), Eleusine flour, sorghum flour, fresh or dried cassava.

For purely administrative reasons, Serere being primarily a cotton-breeding station, all cotton seed allocated for stock-feed is now put through a hammer-mill to destroy its viability, and the practice during the past 18 months has been to put all dried foodstuffs, including cotton seed, through such a mill, then to weigh out the correct proportion of each, and cook all together with a little water. The resulting thick gruel is very palatable and is relished by all stock. In this way none of the cotton seed is wasted, as would happen if it were fed separately.

Other valuable foodstuffs when in season are sweet-potato tops, which have a food value equal to that of fresh lucerne, and the dried straw from groundnuts (*Arachis hypogea*), cowpeas (*Vigna sinensis*), and tepary beans (*Phaseolus acutifolius*), all of which are grown locally and can be collected at time of harvesting the crops, and stored in stacks until required. Stored in this way, they form a useful addition to the ration in the dry weather when grass is scarce. It is, however, most important to ensure that the haulms be free from mildew and any taint of mustiness.

Summary

An account is given of the Serere Zebu herd from its foundation to the present time, together with the breeding policy that has been followed.

Full records have been kept for this herd, which now numbers over 300 head, and from the figures available it has been shown that under the conditions described males reach maturity at about 66 months, and females at about 42 months, synchronizing with the age of first calving-down.

Figures for the heaviest and lightest male and female calves are given, and figures based on the birth-weight of 320 calves show that it increases up to the third calf born, and then changes very little until the tenth calf.

The percentage of effective calvings has been 96·8, and amongst other matters described are the intervals between calvings, the effective life of a cow, calf mortality, sex ratio, and carcass percentage for adult stock.

The herd has been milk-recorded since 1942 and the mean yield per cow has been increased from about 90 gals. in 1942 to 200 gals. in 1949. This is believed to be almost entirely due to better management.

Three systems of calf management are compared. They show that calves kept on free range can compare with European breeds in putting on live-weight; calves raised on free range for the first 7 months in their lives are on the average about 80 lb. heavier at 3 years of age than those which are bucket-fed, or which suckle their dams although bucket-fed; and that suckled calves make nearly double the live-weight gains of the free-range calves in the second year of life.

So far three bulls have been tested by their progeny. One of these has produced heifers which give much more milk than the average of the herd.

Acknowledgements

Many officers of both the Agricultural and Veterinary Departments have been associated with the animal husbandry investigations at Serere, but the success of the herd and the results now being obtained are largely due to the efforts and foresight of two officers, R. K. Kerkham and A. L. Stephens, who were responsible for the selection of the foundation stock, and who decided the breeding policy that has been carried on by their successors. Without the careful records and personal notes made by Mr. Kerkham this paper could never have been written. Mr. V. A. Bunge left Serere in September 1949 and his place was taken by Mr. A. F. Brown whose work in bringing the records up to date and in checking the draft is gratefully acknowledged.

The authors also record their appreciation of the interest taken and the help, advice, and encouragement so freely given by members of the Husbandry Committee, and also the help given by Dr. J. Hammond of the School of Agriculture, Cambridge, who very kindly read the paper and made many valuable suggestions.

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IMPROVEMENT OF RICE IN INDIA

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Agricultural conditions where rice is grown.—*Oryza sativa*, the common cultivated rice of the world, is predominantly a crop of Asia, 95 per cent. of the world's rice area of 205 m. acres being concentrated in SE. Asia, extending from west Pakistan to Japan. In India rice occupies about 75 m. acres, representing 30 per cent. of the cultivated area and the largest acreage under rice in the world with production of about 22 m. tons of rice. The crop thrives best under conditions of high temperature and abundant moisture. Its cultivation is mostly concentrated in river valleys and deltas and low-lying coastal areas in S. and NE. India. Rice is grown under widely varying conditions of soil, humidity, altitude, and latitude. The pH of rice soils varies from 5·0 to 8·5.

Though over large areas only one crop of rice is taken yearly, two or occasionally even three crops a year are grown in special localities, where the winter temperature is not low and irrigation facilities are available for over 7 to 8 months. The bulk of the crop is a winter one, i.e. sown in June and harvested in November–December, but rices are also grown in other seasons, harvesting taking place in summer and autumn. The crop may be of 80-days' duration, or may take 200 days to mature, depending on the variety grown.

The rice crop is usually classified either as 'wet' or lowland rice and 'dry' or upland rice. The 'wet' rice occupies low areas where water is plentiful throughout the rice season; the varieties grown are generally of long duration, i.e. 150–180 days. Upland rice, on the other hand, is always rain-fed and varieties of shorter duration of 90–125 days are usually grown. Lowland rice, due to copious and more assured water-supply, outyields upland rice.

The present average yield of about 800 lb. of clean rice per acre over the whole area of 75 m. acres is very low, but it is higher, 1200–1500 lb., in areas with better water facilities and where the crop is manured. In recent crop competitions under intensive cultivation, yields of 4,000–6,000 lb. of rice have been recorded, which shows the potentiality of some of the areas.

Botany of the rice plant.—The genus Oryza includes 23 species [1], of which 21 are wild and 2 cultivated, viz. *O. sativa* and *O. glaberrima*; the former is found all over the rice-growing areas of the world, but the latter is confined to tropical west Africa. The two cultivated rices are diploids ($2n = 24$) and the wild rices are either diploids or tetraploids. Nandi [2], Ramanujam [3], and other workers regard *O. sativa* as a secondary allo-polyploid, having been derived from an original with a basic chromosome number of five. *O. sativa* comprises a wide range of forms, differing in habit, grain-size, habitat, maturity period, &c. The diversity in this species has led to the belief that in all probability *O. sativa* is

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a composite species. Roschevicz [4] and Porters [5] consider *O. sativa* of polyphyletic origin. Though the ancestry and origin of rice cannot be fixed with certainty, India and Indo-China might well be the countries where *O. sativa* first arose [6]. The varietal diversity is nowhere so great as in India, and it is here that the wild species *O. sativa* var. *fatua* occurs in abundance. This wild rice approximates very closely to the cultivated rice, and its area of distribution in India and Indo-China coincides with areas of the most ancient cultivation of rice. Fatua is considered to be the immediate progenitor of the cultivated rices of the Sativa species. Rice being the oldest cereal under cultivation in India, the centre of its origin cannot be determined, but a particular area still exists in the Orissa and Madras States, which may prove a secondary centre of origin owing to the great varietal diversity still to be found in this area. A detailed survey of this area is under consideration.

Problems of Improvements

The main problem in India, as also in all rice-growing States, is the production of high-yielding varieties, multiplying and putting them into cultivation over large areas as quickly as possible. Among other problems may be mentioned breeding for earliness, stiff straw, resistance to diseases, and in certain localities breeding for deep-water conditions, resistance to flood and salinity, &c. As a complement to breeding, improvement of cultural and manurial practices are very important, as these affect yield profoundly.

Breeding for high yield.—Systematic rice-breeding first started in India some 40 years ago in Bengal and Madras, and was taken up in other States much later, chiefly owing to the encouragement and financial aid they received from the Indian Council of Agricultural Research since its inception in 1929. In view of the significant role played by rice in the economy of the nation, and recognizing the urgent need of furthering intensive research, in 1946 the Government of India established the Central Rice Research Institute in Cuttack, where fundamentals and problems of a wide interest are tackled.

The results of breeding for high yield carried out in the country have been spectacular, and a large number of improved varieties, giving on an average an enhanced yield of 12 to 20 per cent., have been obtained. These superior varieties, numbering about 284 for the whole country, are mostly isolations from naturally variable populations, only 27 of them being produced by hybridization, as shown in Table 1.

Hybridization has been intensified and a very large number of crosses is now under study in different States. In these the main objective is still high yield, but other considerations are also kept in view. Though almost all the improvement in yield has been obtained by selection in natural population, the scope for further improvement by this method has by no means been eliminated. As environmental conditions vary enormously in India, the varietal diversity is very great and thousands of varieties are grown in different parts of the country. So far, the improvement of the most widely cultivated varieties has been tackled in large concentrated tracts, but there are still large tracts in various States where

the variability in the natural population has not yet been sufficiently exploited. This enormous variability, resulting in thousands of varieties each suited to particular condition of soil, season, rainfall, &c., is both an advantage and a curse; it has led to the low adaptability of rice varieties, breeding has to be localized, and a large number of improved varieties have to be evolved.

TABLE 1. *High-yielding Varieties Produced in the More Important Rice-growing States of India*

State	Rice area (million acres 1949–50)	Improved varieties*				Yield of unhusked rice (lb. per acre)
		Sel.	Hy.	Intro.	Total	
Bihar	13·8	7	..	..	7	1,830–2,050
Madras	10·6	91	10	..	101	1,800–4,200
West Bengal	9·7	48	5	1	54†	1,500–3,400
Orissa	9·5	20	..	..	20	2,200–3,200
Uttar Pradesh	9·0	17	3	1	21	2,000–3,400
Madhaya Pradesh	8·8	14	5	..	19	1,100–2,000
Assam	4·0	38	3	..	41†	1,760–3,920
Bombay	3·0	20	1	..	21	2,000–2,700
		255	27	2	284	

* Sel.: Strains evolved by selection in natural populations.
Hy.: Strains evolved by hybridization.
Intro.: Introductions.
† Total number of improved varieties evolved in undivided Bengal and Assam.

Breeding for better yield has been greatly intensified all over the country with the provision of more trained personnel and better facilities, and is now being vigorously tackled in some sixty-one research stations distributed all over the country. Ramiah [7] has summarized the present rice-breeding activities in India and has reported new improved varieties in Madras, Uttar Pradesh, Orissa, Assam, and Bihar States, the objectives being suitability for high altitudes, better milling quality, high nutritive value, varying life-periods, &c.

Problem of wild rice.—Natural hybrids between cultivated rice and the wild rice *O. sativa* var. *fatua* occur as weeds in cultivated fields and cannot be distinguished until the ear-heads appear, when spikelets shatter even before the grains are fully ripe. It is estimated that the incidence of wild rice in the State of Madhaya Pradesh alone is from 3 to 16 per cent., causing a minimum loss of about 2 m. rupees in money-value in the $3\frac{1}{2}$ m. acres under broadcast rice in this State. This problem of wild rice exists also in the States of Bombay, Orissa, Bihar, and Punjab. The problem, successfully solved in Madhaya Pradesh for the first time, is being tackled similarly in other States. The solution consists in transferring to the local variety a pigment gene (anthocyanin) from specially pigmented varieties, so that hybrids with wild rice in the early stages can easily be identified and removed at the time of weeding.

Breeding for earliness.—As previously stated, there is enormous variation in the life-periods of rice grown in India, ranging from 80 to 200

days. There are hundreds of early varieties grown in different parts of the country, as, for example, *Kaurs* and *Kuruvais* of Madras, *bealis* of Orissa, *Aus* of Bengal, *Sathi* of Uttar Pradesh, &c. Earliness is an extremely valuable character provided it is not associated with low yield. Experience has, however, shown that earliness can be combined with good yield. In Madras and Bengal yields of 3,000 lb. of grain per acre of some improved early varieties are not uncommon. It is more the season of growing and the fertilizer practices that determine yield, and not necessarily the life-period of the crop, though in the same season a variety with long duration, not more than 160 days, may yield better than an early maturing one.

The growing of an early crop is a necessity in tracts where double cropping of rice is practised. Since a large part of the rice area in the country is mainly dependent on rainfall, there is urgent need to intensify breeding for earliness combined with satisfactory yield. This is also important if the period of water-availability should be put to the maximum use. From this point of view, the large collection of genetic stocks maintained at the Central Rice Research Institute is being carefully combed out for good yielding, early maturing varieties suited to local conditions. The performance of some Indian and foreign varieties in the collection has proved suitable under Cuttack conditions.

Some of the Chinese rices have shown great promise. Two of the Chinese varieties, which have done well at Cuttack, are reported to yield as high as 5,000–6,000 lb. per acre in the Kashmir valley, and are now under large-scale distribution there. They, however, do not mature there so early as at Cuttack owing to the high altitude and cooler climate. An early maturing high-yielding selection from rice of Chinese origin has become popular in Uttar Pradesh and is reported to yield over 3,000 lb. per acre. A selection from a Chinese variety introduced in Bihar from Uttar Pradesh has done well there and is popular with the cultivators.

Besides sifting the collection of genetic stocks for early maturing, high-yielding varieties, hybridization for this purpose has also been undertaken at the Cuttack Institute. Sathi, a local early maturing variety, and a Chinese variety have been crossed to local improved types and the F_2 generation of these crosses is now under study.

Inter-racial hybridization.—Although cultivated rice, practically the world over, belongs to a single species, *O. sativa*, two geographical races are recognized: *O. sativa* var. *japonica*, and *O. sativa* var. *indica*; the former is cultivated in Japan, Korea, and other rice-growing areas of the subtropics, the latter in India and the rice-belt of the tropical Asian countries.

The Japonica rices yield high, respond well to intensive manuring, have short non-lodging straw, bold type of grain, and higher percentage of rice to unhulled grain, whilst the Indica rices are much lower in yield generally, cannot stand heavy manuring, but are hardier and more resistant to unfavourable conditions.

The Japonica rices when introduced in the Indica zone are a failure, and vice versa: though Japonica rice may not be suitable for direct introduction, it may be possible to exploit them as parents in an attempt to step up the yields in the Indica zone. With this object, a comprehensive

and intensive programme of hybridization between the Japonica and Indica varieties has been undertaken at the Cuttack Institute. The scheme embraces the crossing of 8 selected Japonica varieties obtained from Japan with 64 Indica varieties from India and 8 other Asian countries, viz. Burma, Ceylon, Indonesia, Indo-China, Malaya, Philippines, Pakistan, and Thailand. The crossing, in the various Japonica × Indica combinations, is being done at Cuttack. The F_1 performance will be studied here and the seed of the next generation will be sent to the respective Indica parent countries for study and selection, on the principle that breeding is best tackled in the individual tracts itself. The whole programme of inter-racial hybridization is being financed partly by the F.A.O. and partly by the Indian Council of Agricultural Research. Though difficulties due to sterility may be expected, the work does appear to be one of the ways of tackling the problem of producing early maturing varieties with high yields.

Breeding for flood- and salt-resistance.—About 4½ m. acres in India are subjected to floods and salt-water inundation. Physiological studies by Parija [8*a*, 8*b*] and Alam [9] have shown that resistance to submergence and salinity may be induced by certain pre-treatments of seed. In the past, breeding of varieties resistant to these conditions has not been done to any appreciable extent, but a co-ordinated programme is being taken up with finances partly provided by the Indian Council of Agricultural Research.

Breeding for disease-resistance.—Blast (*Piricularia oryzae*) is the most important disease of rice. The problem of breeding strains resistant to this disease was taken up as early as 1926 [10], and an intensive programme of breeding has since been pursued, in which the rice-breeder and the mycologist have co-operated, and a range of varieties highly resistant to Piricularia with all the desirable agronomic features has been produced. Two new varieties, CO.25 and CO.26, are notable examples that are found to be resistant even under intensive manuring with nitrogen, and this work of Madras can compare favourably with any similar breeding project in any part of the world. These varieties are now being grown extensively in cultivators' fields. Though the disease is prevalent all over India, owing to variable requirements, mainly seasonal, in different parts, the resistant types of Madras cannot be grown everywhere. They are rather late-maturing, taking six months, whereas the need is for resistant varieties of much shorter maturity period. To meet the needs of the States a vigorous programme of hybridization has now been taken up. To help in this programme, work is in progress at the Cuttack Institute, to discover resistant parents from out of the collection of genetic stocks, the parent carrying the resistant character used in Madras work being too late maturing for other States. Mention may also be made of varieties, evolved in Bombay State, that are highly resistant to blast [11].

Breeding for resistance to insect pests.—Though rice varieties do exhibit considerable variation in their resistance to particular insect pests, very little actual breeding for insect-resistance has been done. One example is the production of strains resistant to the attack of the rice-bug

(*Leptocorisa varicornis*) carried out in Uttar Pradesh. Heavy-yielding varieties subject to the attack of this insect were crossed to a very early variety called Sathi which has enclosed ear-heads. Selections with partially enclosed ear-heads resistant to the rice-bug have been obtained. These were somewhat later in duration than Sathi and yielded 20–25 per cent. better than this parent. From Bombay State [11], improved high-yielding varieties moderately resistant to *Pachydiplosis oryzae*, resistant to *Leptispa pygmea* (blue beetle) and to *Sitotroga cerealla* (store moth) are reported.

Breeding for quality.—The conception of quality of rice varies with different interests and may refer to size, shape, and colour of grain, or taste, flavour, and appearance of the cooked product, or the milling and storage properties of grain. Real quality should, however, be based on the nutritive value of the grain, and improvement in quality should imply better and more nutritious varieties. A large part of the proteins and mineral constituents of the rice grain is located in the external layers, namely, the bran and the embryo. There is considerable variation in thickness of the bran-layer. Ramiah [12] has shown that coarse grains have a thicker bran-layer than fine grains, and it has been shown that coloured and coarse-grained rices are more nutritious [13]. Work in Madras has shown that the protein-content can be increased by judicious manuring of the rice crop (Ramiah, in press). So far, no emphasis has been laid on the nutritive value of the grain in breeding programmes, and coarse and coloured rices have been relegated to the background. The examination of existing natural variability in nutritive quality of rices does show a large scope for breeding for better quality.

Improvements in breeding technique.—Although the value of secondary selection is recognized and practised in breeding a crop like cotton, in a self-fertilized crop like rice secondary selections in isolations made from natural populations have not been considered necessary. Efforts have been concentrated only on 'spotting the winners' among the primary selections made, as it is considered that once a superior primary selection has been isolated, all the improvement possible had been reached, and no scope was left for further improvement by selection in its progeny. When it is remembered that characters that either contribute to or control yield are polygenic, it is likely that genetic variability in these characters is not fully exploited by the rice-breeding technique now commonly employed.

In India the procedure of rice-breeding has been to break up the population into its component morphological types, either by isolating from the population all plants showing variation in morphological characters, such as pigmentation in plant-body, grain-size, absence or presence of awns, and starting pure lines of such morphological types as bred true; or by selecting from the population as many plants as possible that look alike morphologically and are similar to the type in general cultivation. In either case further work consisted in determining the most prolific of the primary selections thus made and by multiplying and distributing it.

The value of secondary selections in rice-breeding is being investi-

gated in this Institute. The results so far available do appear to show that secondary selection could be profitable in the case of some varieties. In one case, bulks made of superior and inferior progenies in a family showing variability have shown a difference of 13 per cent. in yield.

Breeding for different levels of soil fertility.—It has been advocated of late that in order to get the best out of breeding it should be done according to soil fertility conditions under which the strains evolved are to be grown, as strains bred under rich soil conditions may not be suitable for poor soil conditions, and those suited to poor soil conditions may not be able to utilize to the best advantage the rich soil conditions provided. This problem is receiving some attention at the Cuttack Institute. In the first year selections were made in two local varieties grown under two levels of soil fertility. Next year, 100 selections from each level of fertility were grown in a split-plot layout in duplicate both under manured and unmanured conditions. The results show that although selections, whether from high-fertility or low-fertility stock, were on the average significantly superior in yield to the bulk, the difference between the two series was not significant. Further work is in progress.

Discriminant function.—In order to find out if selections of varieties based on yield components such as ear-bearing tillers, number of grains per ear, weight of 1,000 grains, in addition to or alternative to yield, would be better than selection based on yield alone, the performance of twenty-five medium varieties was studied. The results obtained are given below.

Characters taken	*Discriminant function*	*Efficiency of discriminant function compared to selection on yield alone*
Ear-bearing tillers (x_2) No. of grains per ear (x_3) Wt. of 1,000 grains in gm. (x_4)	$Y_1 = 1{\cdot}702074\ x_2 + 0{\cdot}091157\ x_3 + 0{\cdot}334661\ x_4$	96·8 per cent.
Same as above, plus single plant yield	$Y_2 = 0{\cdot}778661\ x_1 + 0{\cdot}250734\ x_2 + 0{\cdot}018328\ x_3 + 0{\cdot}058584\ x_4$	100·2 per cent.
	x_1 = yield of single plant	

It will be seen that selection based on the components of yield is not more efficient than selection based on yield alone. The utility or otherwise of discriminant function for rice-breeding work is being further investigated for making selections within a variety and for making selections in segregating material.

Genetics of rice.—In India, though the rice crop has been receiving the attention of crop botanists for the past four decades or so, they have been engaged primarily in breeding superior yielding strains of rice, and genetical studies on the crop was incidental to their work. Despite this limitation, India has made substantial contributions to our knowledge of the inheritance of various characters of this crop.

Though the work done deals mostly with genes having large individual effects in the plant-body, such as occurrence of pigmentation, chlorophyll

deficiencies, and kernel colour, attention has also been paid to such physiological and quantitative characters as spikelet sterility, duration, and grain-size. Hutchinson and Ramiah [14] have listed the various characters studied and the nature of their segregation; later Kadam and Ramiah [15] summarized the genic situation in rice up to the year 1942.

Among plant characters, the inheritance of pigmentation in the plant organs has received most attention from workers in India, and a large number of genes has been identified. Investigations now in progress at the Cuttack Institute have been undertaken with a view to determine the number, role, and interrelationship of the genes responsible for pigmentation, and to determine the pigmentation pattern, if any, in the rice plant.

The genic analysis of polygenic characters in rice is practically an unexplored field. This has been due to their complicated nature and difficulties in finding a suitable technique. Now that Mather has shown the way to study polygenic characters, interest in them has been aroused and study of grain-size and plant-height are in progress at Cuttack.

In producing artificially induced rice mutations, Ramiah and Parthasarathy [16] were first in the field in India. By the use of X-rays they produced a large number of mutations. Thirty-six mutations affecting characters like size and habit of plant, size and arrangement of grain in the panicle, and spikelet sterility; and sixteen chlorophyll mutants were isolated. The cytogenetics of some of these mutations have been studied. One of the mutants produced proved to be of economic value. This has a slightly shorter stature with a larger number of tillers than the original parent material and does well in rich soils where the problem of lodging is serious [17].

Manuring.—Indian soils are generally deficient in nitrogen and organic matter. Many manurial experiments have been conducted all over the country and the results have been summarized by Sethi [18], Ramiah *et al.* [19], and Sethi *et al.* (in press). The application of nitrogen either in organic or inorganic form has invariably given an appreciable increase in yield: the response, however, varied in different places according to the rate and method of application, the nature of the soil, and its base exchange capacity. Further studies are in progress at Cuttack to determine (i) the optimum dose of the most important nutrient, nitrogen, (ii) the comparative efficiency of different organic and inorganic fertilizers, (iii) the best method of application, (iv) the effect of continuous application of ammonium sulphate over a series of years on the soil and rice yields, and (v) whether the harmful effects, if any, could be corrected by applying organic matter and lime in combination with ammonium sulphate.

Rice soils though deficient in phosphates do not give appreciable response to its application except in certain specific tracts. The cause of this is not understood and is under investigation.

Inorganic nitrogenous fertilizers.—Of all the inorganic nitrogenous fertilizers tested, ammonium sulphate has proved to be the most effective. The nitrates of sodium and potassium, and calcium cyanamide are definitely inferior, but other ammonium fertilizers like ammonium

nitrate, ammonium phosphate, and urea compare favourably with ammonium sulphate. The experiments with different fertilizers were conducted at different locations and there was a considerable variation from year to year in the relative effect of various fertilizers, so that the results are not strictly comparable. Nevertheless, they give certain definite indications and the relative rating for various fertilizers as measured by the response obtained is given in Table 2.

TABLE 2. *Relative Efficiency of Various Nitrogenous Fertilizers taking Ammonium Sulphate as 100*

Fertilizer	*Relative rating*
Ammonium sulphate	100
Ammonium nitrate	92
Ammonium phosphate	86
Urea	82
Calcium cyanamide	64
Potassium nitrate	44
Sodium nitrate	40

The data indicate that the ammoniacal forms of nitrogen are more efficient than the nitrate forms. The laboratory studies of Dastur and his co-workers [20, 21] also indicated that in the rice plant absorption of ammoniacal nitrogen is greater during the early stages of growth and that of nitrate nitrogen during the later stages.

The economic and efficient application varies with the initial fertility status of the soil. Varying results have been obtained, but the optimum rate ranged from 20 to 60 lb. of nitrogen per acre. On an average there is an increasing response up to 40 lb. of nitrogen per acre given as ammonium sulphate, beyond which the response declines. With a dose of 20–30 lb. of nitrogen per acre, the increase in yield of about 300–500 lb. of grain or about 15–16 lb. of grain for every lb. of nitrogen applied may be expected.

Organic manures.—In the high temperatures of tropical regions, soil organic matter decomposes rapidly, and there is therefore greater need of replenishing its organic matter in the soil than in the temperate regions. This is usually done by applying cattle manure, but the quantity available in the country is not enough, and there is also wastage due to the inefficient storage practices and burning of the dung as fuel. Green manuring has proved to be most beneficial and is possibly the cheapest means of adding organic matter; and it is quite feasible in irrigated areas. An average crop of *Dhaincha* (*Sesbania aculeata*) or sunn hemp (*Crotalaria juncea*) gives about 8,000–10,000 lb. of green matter, which supplies about 40 lb. of nitrogen per acre besides the organic matter. The experimental data indicate that when this quantity of green matter is incorporated in the fields it is not necessary to supplement it with any inorganic fertilizer. Oil-cake, of which there are several kinds, is another source of nitrogen, and on an equal nitrogen basis it is as efficient as ammonium sulphate, but at present price-levels ammonium sulphate is the more economical. For the rice crop, cattle manure or compost

applied alone does not give as high a response as ammonium sulphate, oil-cake, or green manure, but the fact that it is locally available, though not in sufficient quantities, is an advantage.

Use of combined organic and inorganic fertilizers.—Experiments with ammonium sulphate applied in combination with cattle manure or compost have been conducted at Chinsurah (West Bengal) and at Cuttack. At Chinsurah graded doses of ammonium sulphate to supply 0, 30, 60, 90, and 120 lb. of N per acre were applied alone, and also in combination over a basal dressing of 4 tons of compost per acre, which is equivalent to 40 to 50 lb. N per acre. The experiment was conducted for three years, 1946–9, and the data obtained are given in Table 3.

TABLE 3. *Average Yield of Rice per Acre in lb. after Application of Ammonium Sulphate (Chinsurah Farm—1946–7 to 1948–9 —from Progress Reports)*

Basal organic dressing	*Ammonium sulphate applied as top-dressing*				
	0	*30*	*60*	*90*	*120*
No compost . . .	2,011	2,489	2,386	2,352	2,242
Compost at 4 tons per acre .	2,252	2,629	2,585	2,156	1,937
Mean	2,132	2,559	2,486	2,254	2,090

Thus the yield increases up to 30 lb. N per acre, thereafter declining, and at the highest rates it is less than the control. The quadratic component of the regression of yield on the nitrogen level is significant. The corresponding yield : nitrogen-dose curve can be represented by the equations:

(*a*) No compost $Y = 2{,}084{\cdot}44 + 10{\cdot}91\,x - 0{\cdot}08\,x^2$;

(*b*) Compost at 4 tons per acre $Y = 2{,}258{\cdot}60 + 15{\cdot}99\,x - 0{\cdot}16\,x^2$,

where Y is the expected yield and x is the nitrogen in lb. per acre.

From the above equations the average response of grain per acre for every lb. of nitrogen for different levels of ammonium sulphate is calculated and given in Table 4.

TABLE 4. *Response of Grain in lb. per Acre for every lb. of Nitrogen Applied*

Ammon. sulph. N per acre	*No compost*	*With compost at 4 tons per acre*
10	10·1	14·4
20	9·3	12·8
40	7·7	9·6
60	6·1	6·4
80	4·5	3·2

These figures show that the response to ammonium sulphate is better when applied over a basal dressing of compost. It is of interest that the maximum yield of 2,629 lb. per acre obtained with compost is not

attained by 'no-compost' plots, even by an increase in the level of ammonium sulphate. These also indicate a greater rate of decline in the yield of compost-treated plots with a further increase in the nitrogen-level beyond the dose corresponding to the maximum yield. Similar results have also been obtained at Cuttack and the experiments are still in progress.

Rational method of applying ammonium sulphate.—The present method of applying sulphate of ammonia to rice throughout India consists of spreading the fertilizer on the surface of the wet soil. The work of Pearsall [22] has shown that under swampy and aerobic conditions of rice-soil, only the upper soil layer in contact with water is oxidizing, and the lower layer reducing, so that immediately after applying ammonium sulphate to the surface, the ammonia is partly absorbed by the rice-plant and the rest is oxidized to nitrates which leach down to the lower reducing layer and either N or NO is lost. In Japan, two-thirds of the nitrogen as ammonium sulphate is applied to the dry soil 2–3 in. below the surface a day before the water is let into the field for puddling and transplanting; the other third is applied later in the form of pellets or balls thrust into the soil 2–3 in. deep. At the Cuttack Institute this 'dry' sub-surface application is being tested in comparison with the customary 'wet' surface application [23]. The yield response for various treatments is given in Table 5.

TABLE 5. *Average Response of Grain in lb. per Acre for every lb. of Nitrogen Applied*

	'Dry' application	*'Wet' application*
Medium land . .	14·2	9·4
Lowland . . .	19·3	11·4
Mean . . .	16·8	10·7

Thus the dry method of applying ammonium sulphate is more efficient than the usual wet application.

The application of ammonium sulphate in the form of pellets thrust 2–3 in. deep one month after planting has also been tested against the usual surface application with the following results (Table 6).

TABLE 6. *Yield per Acre for Deep Layering and Surface Application*

	Yield in lb. per acre	
	grain	*straw*
No nitrogen (control) .	1,575	1.926
Surface application . .	1,698	2,089
Deep layering. . .	1,895	2,395

Seed-soaking with phosphatic manures.—To find out whether a more efficient utilization of P_2O_5 could be made by pre-soaking the seeds with

nutrient solutions rather than by direct application to the field, experiments have been conducted at Cuttack and Coimbatore (Madras). Abichandani and Ramiah [24] have reported that of the twelve nutrient solutions tested, dipotassium phosphate and tripotassium phosphate gave an increased yield of 21·72 and 15·4 per cent. respectively over the untreated seeds. Further work on these lines is under way. In this connexion the use of the phosphates for a green manure crop, intended to be ploughed in for the rice crop or to the legume crop which is grown in rotation with it, appears to give promising results.

Improvement in cultural practices.—The preparation of the land and the method of cultivation depend on the type of soil and the amount of rainfall. The land is usually ploughed and kept ready, and with the first monsoon or pre-monsoon showers in May–June the crop is sown broadcast at the rate of about 80 lb. per acre. In broadcast fields the preparation of land is never thorough with the bullock-drawn implements as it is difficult to deal with heavy soils in dry condition. Such incomplete preparation of the land results in a greater profusion of weeds, and usually the weeding receives insufficient attention. In case of more assured and timely irrigation supply, a nursery is raised and the seedlings are transplanted in the previously puddled field. Transplanting, though an arduous and labour-consuming process, has a direct beneficial effect on yield and incidentally keeps down weeds. The experimental results all over the country indicate the definite superiority of transplanting over straight sowing, the increase being from 15 to 30 per cent. Besides, there is greater economy in seed: for transplanting only 25–30 lb. of seed per acre is used, which is about one-third of that used in broadcasting. Whilst transplanting is practised in areas of assured water-supply, straight sowing still obtains in about 75 per cent. of the area where the crop has to depend entirely on rains, and where there is shortage of labour in the busy part of the season.

Agronomic experiments to determine the optimum season for sowing, the spacing, the age of seedlings, and the water-requirements with special reference to new varieties, are always conducted at the various experimental stations. The plantings early in the season during May–June are conducive to higher yields, but the time of planting very much depends upon the break of the monsoons. When the monsoon is delayed so also is the planting and with few exceptions most varieties suffer in yield as a consequence.

Spacing and rate of planting also depend on the variety, type of soil, and the time of planting. For early maturing varieties a spacing of 4–6 in. is found to be best, but for long-duration varieties a wider spacing of 9×9 in. or even 12×12 in. is desirable. Too wide a spacing affects yield adversely, owing to the reduction in total number of ear-bearing tillers per acre, and to the uneven ripening and late tillers producing immature grains. The yield is the product of the number of ears and number of grains per ear in a unit area. Though with wider spacing large ears and more tillers per plant are produced, they do not compensate for the reduction in population density per unit area.

Under the prevailing rice-growing conditions, particularly in river

deltas, it is not possible to grow rice and other dry crops side by side, and therefore a well-balanced rotation is not possible and the growing of rice year after year is inevitable. In certain rice areas some quick-growing leguminous crops like green grams (*Phaseolus rheus*), black gram (*Phaseolus mungo*), gram (*Cicer arietinum*), or khesari (*Lathyrus sativum*) are grown after the harvesting of the rice crop; but the yields of such crops are low, and since they are grown for seed their value for enriching the soil is rather doubtful.

The knowledge that the rice crop benefits by the incorporation into the soil of large quantities of organic matter has long been utilized by the Agricultural Departments, and the practice of growing leguminous crops for green manuring in the season is gradually extending. Though in some areas of India with irrigation facilities for 8–9 months growing of two crops of rice in succession on the same land during the year is common, it is not adopted in all the areas. Experiments at Cuttack have shown that it is possible to grow not only two crops of rice but also a green-manure crop in addition, thus nearly doubling the output. Where the lay of the land allows it, a crop of groundnuts (*Archis hypogeae*) can be rotated with rice and the following yield of rice is quite high.

It is established that response of rice to manures and fertilizer has a direct relation to optimum and timely supply of water. Under the existing conditions only about 20 per cent. of the rice crop has canal-irrigation facilities, the remaining area depending solely on the rainfall, mostly from the south-west monsoons. There will be greater scope for the efficient use of water when the new irrigation projects are completed.

A considerable loss of crop occurs from diseases, insects in the field, and in store. There is great scope for breeding for disease-resistance. The intensification of the programme of spraying insecticides against insect pests is a very effective line of attack, but the enormity of the problem is the limiting factor.

To conclude, future progress in improving rice production depends on the intensification and application of knowledge already available in all areas. Though there is great scope for intensifying for special requirements, immediate scope consists in properly fertilizing the crop; and more work on soils is needed so that a manure schedule can be drawn up for each tract. That phenomenal yields of even 8,000–10,000 lb. of grain per acre can be obtained has been established by the recent crop competitions. This has been achieved by enterprising and enlightened rice-growers making use of all available knowledge. An all-round increase in production would therefore depend on how effectively we can provide the necessary facilities and supplies to all rice-growers, small and large, and create an interest and incentive in them to increase their present level of production.

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THE NODULATION OF ANNUAL LEGUMES IN ENGLAND AND NIGERIA: PRELIMINARY OBSERVATIONS

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NEARLY all detailed observations on the nodulation of leguminous plants have been made in the temperate zones, and but little work on the subject has been done in the tropics. From time to time it has been suggested that the degree of nodulation on tropical legumes is not as great as in temperate climates; a typical observation is that of Demolon [1], who had 'frequently noted a total absence of nodules' on such plants in hot countries. But such remarks have generally been made verbally at meetings of tropical agriculturists, for scientists have been chary of committing themselves to paper in the absence of quantitative evidence on the point. This lack of knowledge on an important subject has stimulated the present attempt to obtain some preliminary comparative figures for nodulation in England and Nigeria.

Since even in England it is difficult to find any data available on average weights of nodules produced by leguminous crops under field conditions, the first step needed was to obtain an estimate of such figures. Many pot- or water-culture experiments have been carried out to determine the effect of various factors on nodulation; but the conditions for the root-system are here so special that they cannot be used to predict the rates of nodulation to be expected on the farm. The most relevant data from such experiments concern the influence on nodulation of different levels of nutrients and water-supply in the soil. The experimental evidence up to 1932, summarized by Fred, Baldwin, and McCoy [2], shows that nodulation tends to be favoured by low nitrogen and high calcium and phosphate in the root medium. There is also much evidence that nodulation is favoured in wet soils; indeed, for soya beans Wilson [3] found that nodulation was optimal in a mixture of one part soil and three parts water. The same author [4] later recorded the observation that Phaseolus plants may 'shed' nodules when the water-content of the soil is reduced. But no studies seem to have been made hitherto on the effect on nodulation of agricultural treatments such as spacing and sowing-date. It was therefore necessary to collect new data on the average rates of nodulation in agricultural crops, and to discover by experiment how far these might vary with agricultural practice.

Phaseolus vulgaris was selected as a standard crop for some of these observations, partly because it is easily and quickly grown, and partly because it grows equally well in both the temperate and tropical environment (one particular variety, 'Canadian Wonder', is quite commonly grown in both). At the same time it must be remembered that Phaseolus is unusual among Leguminosae in its nodulation relationships. Many workers have found that inoculated plants of *P. vulgaris* do not always give a higher yield than unnodulated plants; indeed, Frank [5] went so

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far as to say that in this case the relation of bacterium to host was one of pure parasitism rather than symbiosis. Often no nodules at all can be found on a proportion of the plants. Observations on this genus should therefore be regarded as contributing to an understanding of nodule formation without taking into account the secondary effects on plant-growth.

It is not the whole field of nitrogen fixation which is being studied in these investigations. The effect of nitrogen-fixing symbionts on their host plant may be analysed as due to: (*a*) the weight of nodules borne on the plant, (*b*) their longevity, (*c*) their power to fix nitrogen per unit weight and per unit of time, and (*d*) their power to transfer fixed nitrogen to the host plant. Of these four factors, it is only (*a*) and to a lesser extent (*b*) which have been studied in this investigation; but the importance of (*c*) and (*d*) must always be kept in mind in visualizing the whole picture.

Experimental Methods

When plants were to be examined, the soil around them was loosened on four sides with a garden fork of 30 cm. tines; the plant was then lifted gently with the fork, with the root-system as intact as possible. The roots were next carefully washed (generally in the field), and on arrival at the laboratory the nodules were counted and detached with forceps for weighing. This method does not, of course, give the total weight of nodules on the roots, but rather provides an estimate of the degree of nodulation from a sample which comprises (for small annual legumes) by far the greater part of the whole. The technique should, however, enable valid comparisons to be made between different populations of legumes examined by the same method.

Fresh weight was taken as the only feasible method of recording weights of plants and nodules, since in many cases the data had to be collected during short stays at a centre, and oven-drying facilities were not available for the large quantity of material to be examined. Plants awaiting detachment of nodules were kept in damped cloths to reduce the rate of drying, or where a longer interval was unavoidable were stood in water.

A fair criterion for recording 'numbers of nodules' was difficult to establish since in many species the nodules form confluent clusters, and it is hard to decide how many individual nodules have contributed to each, whilst the lower limit of size for what shall be called a nodule is also difficult to define. Moreover, the numbers counted will vary with such factors as the eyesight of the operator and the light he works in. To obtain some definite standards it was finally decided to count every cluster as 'one' nodule, and not to count any nodules which were too small to be detached with fine forceps. The 'number' of nodules recorded thus means little except for comparison with other observations on the same species. This lack of precision is not serious since the number of nodules is of little practical importance compared to their weight; a nodule the size of a pea and one the size of a pin's head are obviously not comparable in biological significance.

The work of detaching and counting the nodules is trying and tedious. With some plants, such as runner groundnuts, the nodules are so small and numerous that to deal with three plants may be a whole day's work for one person; at the other extreme, forty-five plants of *Phaseolus vulgaris* were the most ever dealt with in a single day. This physical limitation severely restricts the number of plants taken in a sample, and made it rarely possible to have large enough samples to satisfy statistical requirements. This work should therefore be regarded as essentially exploratory and preliminary, and not (except in one or two experiments) as giving a statistically complete answer to the problems posed.

Experimental Results

(A) OBSERVATIONS IN ENGLAND

1. *Dwarf Bean* (*Phaseolus vulgaris*). In 1948 some preliminary observations were made with 'Canadian Wonder' beans to determine methods of working and the best age at which to uproot the plants. The beans were sown in Oxford on newly dug-in turf which some years before had been used for allotments for a short time and may or may not have carried crops of Phaseolus. The soil was a freely draining gravelly loam which dried out quickly after rain; the summer was moderately wet and cool. The figures recorded in Table 1 are of interest as showing the lowest weights of nodules obtained in any English observation on this species; on nearly half the plants no nodules were found at all. Possible explanations for this low rate of nodulation might include the freely draining soil, or, if Phaseolus had not been grown on this land before, a scarcity of nodule bacteria. A separate mean weight of nodules per plant was worked out for plants in outside rows, at the end of rows, or next to gaps; this proved to be identical with the mean for plants surrounded by other beans.

TABLE 1. *Nodulation of Dwarf Beans at Oxford, 1948*

Days from sowing	*No. of plants sampled*	*No. without nodules*	*Mean nodule wt. per plant (gm.)*
54	39	17	0·007
87	12	5	0·148

In 1949 a comprehensive experiment with the same variety was laid down at Sandford, near Oxford. The treatments included 3 sowing-dates and 3 spacings, and the plants were sampled at 3 different ages; the experiment comprised 27 plots, with the treatments statistically 'confounded', and 15 plants were dug up as a sample from each plot. The soil was a clayey loam, pH 7·0–7·1, and as far as known had not carried a leguminous crop before (though runner beans had been grown in another part of the field), nor had it been recently manured.

The effects of spacing, as shown in Table 2, may first be considered. The differences between nodule weights at the different spacings were

not significant. The fact that beans planted at a close spacing form at least as great a weight of nodules per plant as at a wide spacing, i.e. a much greater weight of nodules per acre, is perhaps explicable on grounds of nitrogen nutrition. At the closer spacings there will be a greater competition for soil nitrogen, and a low level of nitrogen supply is well known to cause increased nodulation.

TABLE 2. *Nodulation of Dwarf Beans at Different Spacings, Sandford, 1949*

Spacing	*Mean plant wt. (gm.)*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
1 ft. × 6 in.	79·0	0·23	0·29	23·9
1 ft. × 1 ft.	131·1	0·18	0·14	18·6
1 ft. × 2 ft.	180·5	0·14	0·08	15·0

The effects of sowing-date are shown in Table 3, where the differences were significant at $P = 0{\cdot}01$. The steady fall in nodulation as the summer progressed coincided with a gradual drying of the soil, for in this dry summer not enough rain fell to penetrate the soil after April, and during the growth period of the third crop the soil was very dry indeed. The result therefore again suggests that soil moisture is an important factor controlling nodulation in the field.

TABLE 3. *Sowing date and Nodulation of Dwarf Beans, Sandford, 1949*

Sowing date	*Mean wt. of nodules per plant (gm.)*
April 29	0·35
May 29	0·15
June 29	0·06

The three ages at which plants were sampled were 55 days, 85 days, and 96 days from sowing. These times were chosen because the preliminary observations showed that at the first of them all plants which are going to form nodules are likely to have done so, at the second nodule weight is about at a maximum, and at the third some of the nodules are beginning to break down. Interest chiefly attaches to the percentage of disintegrated nodules (as defined by their ceasing to contain firm tissue) at the third sampling in relation to the three different spacings, where the differences were significant at $P = 0{\cdot}05$. The figures in Table 4 show this interaction, by which it appears that at the wider spacings the nodules are shorter-lived. There is not enough evidence

TABLE 4. *Disintegration of Nodules in Relation to Spacing, Sandford, 1949*

Spacing	*% nodules disintegrated at 96 days*
1 ft. × 6 in.	6·7
1 ft. × 1 ft.	21·8
1 ft. × 2 ft.	31·9

to suggest whether this might be due to differing size of plants, to maturity of plants, or to external nitrogen-level at the different spacings.

In the whole experiment, 36 out of the 405 plants dug up, or 8·9 per cent., were found to have no nodules. There was no significant correlation between plant weight and nodule weight, taken over all plants; as already explained, this was not an unexpected result for this species of bean. Variability in nodule weights between plants in the same plot was very high, standard deviations of from 61·8 per cent. to as high as 99·8 per cent. of the plot mean being recorded for individual plots. For this reason it was found convenient to transform the weights to a logarithmic basis for analysis in this and other experiments.

A further experiment was undertaken in 1951 to test whether the effect of sowing-date on nodulation would be the same in a different season. This experiment was laid out in three randomized blocks on the same land at Sandford, and the sample plants were uprooted at 83–87 days from sowing. The differences shown in Table 5 in nodule weights per plant for the different sowing-dates, which were significant at $P = 0{\cdot}01$, are in the reverse order to those of 1949. This result is readily explicable if soil moisture is an important factor favouring nodulation, for the rainfall during the growing-period was successively greater for each of the three plantings. The very high weights of nodules (up to 10 gm. on individual plants and no plant without nodules) might equally be explained by a very wet season. As an alternative it might be advanced that the increase was related to a possible abundance of nodule bacteria due to the land having been under the same crop in 1949.

TABLE 5. *Nodulation of Dwarf Beans sown at Different Dates, Sandford, 1951*

Sowing-date	*Mean plant wt. (gm.)*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
April 30 . .	76·5	2·14	2·80	105·4
May 30 . .	284·5	3·07	1·12	79·1
June 30 . .	230·7	4·47	1·88	176·4

Another example of the relatively high weights of nodules which can be produced was obtained in the same season. A plot of 'Canadian Wonder' beans sown on May 30 near Oxford on a heavy loam and sampled at the same age gave an average weight of 1·80 gm. of nodules per plant from fifteen plants. The highest weight was 3·96 gm. per plant, and as at Sandford every plant bore nodules. Again alternative explanations are available in the wetness of the season, or the fact that Phaseolus had been grown on the land some 3 years before.

2. *Field Beans* (*Vicia faba*). In 1949 samples of twenty flowering plants each were dug up from four crops of winter-planted beans growing on farms of varying soil type round Oxford. Details of the four sites samples were as follows: (*a*) Place: Wytham. Soil: Oxford clay. Beans broadcast at very irregular spacing. Manured with farmyard manure. (*b*) Place: Marston. Soil: Oxford clay. Beans drilled, mean area per

plant 99·5 sq. in. Not manured. (*c*) Place: Culham. Soil: light sandy (Lower Greensand), pH 5·6–6·0. Beans drilled, mean area per plant 104 sq. in. Not manured. (*d*) Place: Kirtlington. Soil: light calcareous with alluvium, pH 6·6. Beans drilled, mean area per plant 70·4 sq. in. Not manured.

TABLE 6. *Nodulation of Field Beans near Oxford, 1949*

Site	*Mean plant wt. (gm.)*	*Mean wt. nodules per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
(*a*) Wytham .	51·8	0·63	1·22	11·7
(*b*) Marston .	86·2	0·94	1·09	23·8
(*c*) Culham .	57·9	0·32	0·55	33·6
(*d*) Kirtlington .	52·1	0·78	1·50	24·1

The striking feature of the results obtained (Table 6) is the low weight, though large number, of nodules on plants growing in the poor sandy soil at Culham. In contrast to the results on Phaseolus there was in every case a significant correlation between plant weight and nodule weight, though the regression at Culham was much steeper than in the other cases. However, in interpreting such data, it should be pointed out that there is no statistical means of deciding whether they imply that plants having a heavy weight of nodules therefore grow big, or that plants which are big attract a heavy infection of Rhizobium because of the wide spread of their root-systems. Slight evidence in favour of the former alternative is given by the Phaseolus spacing results at Sandford; for there the bigger plants carried, as has been seen, no larger *numbers* of nodules than the smaller ones.

No plants in these or any other samples of *Vicia faba* were found to be without nodules. In all four samples the nodules were heavily infested with larvae of the pea weevil *Sitona lineata* Linn., which eat out the inside of the nodules and greatly reduce their weight.

In 1949–50 an experiment of six randomized blocks was laid down at Sandford on the ground previously occupied by the Phaseolus experiment, to determine the relative nodulation of winter-sown and spring-sown beans. The sowing dates were October 15 and March 9 respectively, and the spacing was 2 ft. × 4 in. (96 sq. in. per plant). Sampling was carried out on the winter and spring beans when each was in the early flowering stage and approximately of the same height, i.e. on May 24–29 and June 13–16 respectively. Ten plants were taken as a sample from each plot, and the results are shown in Table 7. The difference in favour of the winter beans for both absolute nodule weight and percentage weight of nodules was significant at $P = 0{\cdot}01$. The correlation between plant weight and nodule weight over all plants (winter and spring) was also significant at the same level.

The comparison between nodule weights for the two sowing-dates was, however, vitiated in this experiment, for in the spring beans the nodules were infested with Sitona, the winter beans were not attacked at all.

TABLE 7. *Nodulation of Winter and Spring Beans, Sandford, 1950*

Sowing	*Mean plant wt. (gm.)*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
Winter . .	212·3	4·70	2·24	88·0
Spring . .	136·2	1·78	1·31	108·8

A further interesting comparison is possible because it happened that on Blocks I and II of the spring beans the infestation was heavy, but on Blocks III–VI it was light to medium. These comparative effects of Sitona together with relevant data from the other experiments are set out in Table 8. In these figures, not only the nodule weight but the weight of plants appears related to the degree of Sitona infestation. Attention to this pest has hitherto been concentrated on the damage done by the adults to the tops of the plants; it is suggested that the damage done by the larvae to the nodules is worthy of more serious consideration as affording a possible explanation of some of the vagaries of bean yields in England.

TABLE 8. *Sitona Infestation and Nodulation of Beans*

Time planted	*Place*	*Sitona infestation*	*Mean nodule wt. per plant (gm.)*	*Mean plant wt. (gm.)*
Winter 1948	4 fields on farms	Heavy	0·67	62·0
Winter 1949	Sandford	Nil	4·70	212·3
Spring 1950	Sandford, Blocks I–II	Heavy	1·35	110·4
Spring 1950	Sandford, Blocks III–VI	Light to medium	2·00	149·1

3. *Peas* (*Pisum sativum*). In March 1950 peas of the dwarf variety 'Meteor' were sown at Sandford in eight plots comprising two 'pseudo-Latin squares' to compare the effect on nodulation of spacing at 2 ft. × 2 in. and 2 ft. × 4 in. Eight plants from each plot were sampled at the flowering stage on June 5–7, and the results are shown in Table 9. The difference in nodule weights at the two spacings is not significant, although both the percentage of nodule weight and the number of nodules was slightly higher at the closer spacing, the results thus corresponding with those previously obtained for Phaseolus. No plants were without nodules; there was again a correlation, significant at $P = 0{\cdot}01$, between nodule weight and plant weight.

An opportunity to assess the percentage of disintegrated nodules did

TABLE 9. *Nodulation of Peas at Different Spacings, Sandford, 1950*

Spacing	*Mean plant wt. (gm.)*	*Mean wt. nodules per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
2 ft. × 2 in.	51·9	1·05	2·02	38·4
2 ft. × 4 in.	44·7	1·16	2·60	33·4

not occur until 107 days from sowing, and then on no more than eight plants sampled at random from each spacing; 73 per cent. of nodules at the closer spacing and 64 per cent. at the wider spacing were disintegrated. The difference, with this small number of plants, was not significant; but the figures give no sign of the same interaction between spacing and longevity that was found with Phaseolus. Breakdown of nodules had, however, been hastened by a slight infestation of Sitona.

A further experiment was undertaken in 1951 to determine the range of nodulation in another season and on different soil types. In this another dwarf early variety, 'Laxtonian', not very different from 'Meteor', was used. Sowing was delayed by wet weather and did not take place till April 23. One plot was planted at Sandford on the land occupied by peas in the previous year, and one a few yards away on land not known to have carried peas previously. A third plot was sown at the University Field Station on a lighter loam than that of Sandford, and a fourth in a garden at Kidlington on a heavy clay (this plot had received a heavy dressing of farmyard manure during the previous winter). Spacing in all cases was at 2 ft. × 2 in., and twenty plants from each plot were dug up 85–87 days after sowing. Unfortunately, in contrast to the previous season, a high proportion of the nodules were already disintegrated at this age and the figures for weight are therefore of little interest except for comparisons within the experiment. A basic point is here raised as to whether, in experiments of this type, comparisons should be made between populations of the same age, or, as far as can be judged, of the same stage of nodular development. Since sampling took place on July 17–19 after a short spell of dry, hot weather, it is possible and would be in accordance with Wilson's findings already quoted [4] that this dry spell had caused early nodule decay. The results are shown in Table 10, where the differences between nodule weights were significant at $P = 0{\cdot}05$, except between the Field Station and the Sandford plot after peas. It appears from the results that nodulation was not favoured on the site where peas had previously grown at Sandford. Although many soil factors might be concerned, weights of nodules were in the order of increasingly heavy soil, in spite of the factor working to the contrary that the heavily manured clay at Kidlington was probably much richer in nitrogen than the lighter soil on the Field Station which produced very poor growth. The correlation between plant weights and nodule weights was again significant on all plots except the third, where many of the nodule weights were too small to be recorded with the technique employed.

TABLE 10. *Nodulation of 'Laxtonian' Peas at Different Sites, 1951*

Site	*Mean plant wt. (gm.)*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
Sandford . .	63·0	0·06	0·10	25·4
Sandford (after peas) .	40·6	0·02	0·05	10·9
Field Station .	32·8	0·01	0·03	10·6
Kidlington .	135·6	0·13	0·10	26·4

(B) OBSERVATIONS IN NIGERIA

The observations in Nigeria were made during a visit, largely occupied by other matters, in July–September 1950, that is during the wet season. They were nearly all made at three centres: Moor Plantation at Ibadan and the Oil Palm Research Station at Benin in the south, and Samaru Experiment Station near Zaria in the north of Nigeria. All three have sandy soils such as are general in Nigeria, but the Samaru soil has more fine sand and less coarse sand than the others; it may also have a lower nitrogen-content, though figures from analyses are too few to be definite. By contrast to the Ibadan and Benin soils, which are very free-draining, the Samaru soil is much more retentive of water and almost throughout my stay there was standing water in the furrows.

1. *Beans* (*Phaseolus vulgaris*). At Ibadan a plot had been planted from seed of a climbing variety bought in the local market. Ten plants sampled showed no nodules at all. Although some plants had produced pods, they were mostly stunted, but this may have been due to severe insect damage; the crop is not much grown in this locality, so is perhaps unsuited to it. At Benin, plants sampled from a plot of 'Canadian Wonder' again had no nodules. These also were stunted plants, and had many eel-worm swellings on the roots and insect damage to the foliage. At Samaru, out of 12 plants sampled from a plot of 'Canadian Wonder', 7 plants had no nodules but the remaining 5 were nodulated, giving an over-all average of 1·6 nodules per plant. The nodules were so small that on no plant did they weigh as much as 0·01 gm. The plants had made reasonably good growth but were the survivors of a population many of which had died; nearly all plants showed eel-worm attack. The nodules seen were unlike those of Phaseolus in England, being small, white, and single instead of clustered.

Two more plots of this species were noted in passing through other places where weighing facilities were not available. At Enugu in south-eastern Nigeria, 4 plants of 'Canadian Wonder' from a market-garden scheme were examined in detail; 2 were unnodulated, 1 had about 30 nodules, and one 6. The nodules were again small, with a stippled surface such as is commonly seen in cowpea nodules and occasionally in Phaseolus nodules in England. At Abakaliki experimental farm in the same region, out of 12 plants of 'Canadian Wonder' 5 had no nodules but the mean was 0·6 nodules per plant; and out of 12 plants from local seed 8 had no nodules but the mean was 0·7 nodules per plant. These nodules again were small, white, and atypical.

It is only possible to draw very tentative conclusions from these figures. Unfortunately in no case was it possible to be certain that Phaseolus, which is not a very common local crop, had ever been grown before on the planted areas. The greater nodulation at Samaru than in S. Nigeria recurs with other crops to be mentioned later. The atypical form of the nodules suggests that where nodulation did occur it may have been with a Rhizobium which is not the normal symbiont with *P. vulgaris*.

2. *Groundnuts* (*Arachis hypogea*). Samples of bunch and runner varieties were examined at Ibadan, Benin, and Samaru. These samples

were mostly of 5 plants (from 3–6), the small number being due to the time taken in examining each groundnut plant. The figures (Table 11) cannot therefore be said to indicate more than that nodulation may vary with locality and variety. The difference between runner and bunch varieties deserves further investigation. The almost identical nodule weight of closely and widely spaced groundnuts (of very different plant weight) from one plot at Ibadan does not contradict the results of spacing experiments in England.

TABLE 11. *Nodulation of Groundnuts in Nigeria, 1950*

Sample	*Mean plant wt. (gm.)*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
Ibadan (bunch) close spaced .	187	0·50	0·26	254
wide spaced .	372	0·51	0·14	223
Ibadan (runner)	474	1·34	0·28	602
Benin (bunch) .	283	0·70	0·25	301
,, ,, .	106	0·33	0·31	86
Samaru (bunch)	197	1·00	0·51	293
,, (runner)	345	2·52	0·73	724

3. *Cowpeas* (*Vigna catiang*). Samples of 12–15 plants were examined at Ibadan, Benin, and Samaru, and the figures obtained are shown in Table 12.

TABLE 12. *Nodulation of Cowpeas, Nigeria, 1950*

Site	*Mean plant wt. (gm.)*	*Mean wt. nodules per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*
Ibadan . .	272	0·38	0·14	27·2
Benin . .	42	0·16	0·39	9·8
Samaru . .	202	1·14	0·56	67·1

4. *Miscellaneous observations.* A few observations made on other crops have been collected in Table 13. The figure for the winged bean (*Psophocarpus tetragonolobus*) is the highest mean weight of nodules

TABLE 13. *Nodulation of Miscellaneous Crops, Nigeria, 1950*

Crop	*Place*	*Mean nodule wt. per plant (gm.)*	*Nodule wt. as % of plant wt.*	*Mean no. of nodules per plant*	*No. of plants in sample*
Velvet bean .	Ibadan	0·80	0·46	8·8	5
Sunn hemp .	,,	0·29	0·14	87·2	5
Winged beans	Benin	1·72	1·38	10·0	5
Soya beans .	Abakaliki	..	..	5·7	12
,, .	Samaru	1·50	1·28	37·2	15
Green gram .	Abakaliki	..	..	11·3	12
,, .	Samaru	0·43	0·31	18·3	12

observed on any legume in Nigeria. The relatively high figure for the velvet beans (*Mucuna aterrima*), which were young plants only 2 months old, is also of interest since this has proved itself in experiments to be the most generally useful green manure crop in Nigeria; unfortunately this and other perennial legumes cannot be sampled when mature by the method used, as the root-systems become much too big to be dug up in their entirety.

Discussion

The figures obtained in these investigations give a lower rate of nodulation for Phaseolus in Nigeria than in England. Of the other crops none in Nigeria reached the weight of nodules attained, either absolutely or as a percentage of plant weight, by some samples of field beans, peas, and Phaseolus in England; though there was some overlapping between the higher Nigerian and the lower English figures. Although the number of plants sampled in Nigeria was not large enough to enable valid comparisons to be made between localities for any one crop, yet the consistently greater nodulation found at Samaru than at stations in southern Nigeria for five different crops does suggest a real difference. This is readily explicable if high soil moisture is the chief field factor responsible for heavy nodulation, for the Samaru soils are heavier and were much wetter in the growing-season when seen than those of the south; though their possibly lower nitrogen-content may also contribute to heavier nodulation. In the same way, if tropical legumes do in general nodulate less than temperate legumes, it may be merely because tropical soils are drier. If nitrogen levels in the soil were the over-riding factor, one would expect tropical soils with their low nitrogen-content to promote heavier nodulation, but this does not at the moment appear to be the case.

Apart from Phaseolus, which is exceptional, plant weight was found to be significantly correlated with nodule weight in those legumes where the samples taken were large enough to provide statistical data, i.e. in field beans and peas. If this is true of legumes in general, and if soil moisture largely determines nodulation, then there should be considerable scope for increasing the yields of leguminous crops by maintaining a high water-content in the soil round the roots. On such postulates it seems open to doubt whether on the already free-draining sands of southern Nigeria the best yields of groundnuts are obtained by growing them on ridges, which still further accelerate drainage, though it is realized that any change might necessitate other measures of erosion control and make harvesting slightly more difficult. The case is quite different in northern Nigeria, where ridging appears to be essential to avoid water-logging in the wet season.

Since indications were obtained that spacing does not affect the weight of nodules borne per plant, so that with a higher plant population there is a greater weight of nodules per acre, it is of interest to note the empirical practice of farmers in many countries who sow leguminous crops closer when they are going to turn them in for green manure than when growing them for seed; though, of course, their motives may

include other factors such as weed suppression, which have to be considered as well as nodulation.

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Summary

1. It has sometimes been stated that leguminous crops tend to be less heavily nodulated in the tropics than in the temperate zones. The present paper describes observations on the weights of nodules carried by some leguminous crops in England and Nigeria.
2. *Phaseolus vulgaris*, the only crop tested in both countries, had lower weights of nodules in Nigeria than in England.
3. Groundnuts and cowpeas, and a few other crops in single observations, had a lower range of nodule weights in Nigeria than did field beans, peas, and Phaseolus in England, though with some overlapping between the higher Nigerian and lower English figures.
4. Variations found in nodule weights within each country tend to support the hypothesis that high soil moisture is a main factor responsible for heavy nodulation in the field. Legumes may nodulate less in tropical soils simply because the soils are drier.
5. In experiments with different spacings, the weight of nodules borne per plant was not found to vary with spacing. A higher plant population would therefore give a greater weight of nodules per acre.
6. In England, much destruction of pea and bean nodules is caused by the insect *Sitona lineata* Linn., whose status as a nodule pest has received little attention but may explain some of the vagaries of bean yields.
7. In Nigeria, nodulation of all crops was heavier on a soil type typical of northern Nigeria than at stations in southern Nigeria.

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THE CHEMOTHERAPY OF PLANT DISEASE

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Introduction.—Until recently the use of chemicals for controlling plant diseases was confined to applications aimed at protecting the surface of the host from infection. The use of protective fungicides has succeeded in combating certain forms of disease, but has obvious limitations. Methods are now being developed which depend on the action of added chemicals within the plant tissues, and it is this systemic type of action that is embraced in the term chemotherapy. The broad distinction between protective and chemotherapeutic treatment is obvious, but in practice borderline cases have been recorded, particularly where chemicals applied as protectants have a limited power of penetration but can be used for the local eradication of established lesions. This type of action is probably chemotherapeutic within the strict definition of the term, but the present account will be confined to chemicals that become systemically distributed within the host. There are many advantages attached to using such chemicals in the treatment of plant diseases. They open up a new field in the control of internal diseases, such as the virus diseases and vascular wilts which, by their nature, are beyond the reach of the conventional protectants. Further, in the field covered at present by protective spraying, application of chemicals that are redistributed within the plant would remove the necessity for complete coverage with its attendant mechanical problems, and would thus promote more effective disease-control.

History—The historical development and scope of chemotherapy as applied to plant disease has already been surveyed in some detail [1, 2] and will only be dealt with briefly. Early attempts, such as the treatment of silver leaf of plums [3] and apple mildew [4], met with no consistent success and did not lead to a systematic study of the problem. The successful control of Fusarium wilt of carnations was reported in 1936 [5], but this also appears to have been an isolated observation. The present interest in the subject dates from the observations of Howard and Caroselli [6, 7] and Howard [8] on the control of bleeding canker of the maple and other hardwoods caused by *Phytophthora cactorum*. This work demonstrated the possibility of using chemicals injected into the sap-stream in the control of diseases of standing trees. The devastation caused by Dutch elm disease (*Ceratostomella ulmi*) among the American elms planted for shade and ornament in most New England towns, lent a special urgency to a study of the control of vascular diseases of standing trees in this area and chemotherapy offered a promising line of approach to this problem. Much of the early work was therefore devoted to the study of vascular diseases of trees with special reference to Dutch elm disease [7–16]. More recent developments have included some success in the control of a bacterial disease of the red kidney-bean [1, 17, 18], some

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virus diseases [19–22], fungal leaf diseases [23–27], and mycelium latent in seed [28]. In the present survey consideration is confined to the attempts to control fungal and bacterial diseases.

Mode of action.—There is little information on the behaviour in the host plant of the compounds used as chemotherapeutants, or on the way in which they affect the pathogen. It is generally assumed that the compounds are translocated within the host to the point of action either unchanged or as degradation products, but the evidence is still scanty. There appear to be three ways in which the active chemicals might reduce disease, namely, by suppressing the growth of the pathogen, by neutralizing any toxic products that contribute to the development of the disease, and by increasing the resistance of the host. It is clear that the actual mechanism of disease-control cannot be elucidated satisfactorily in specific cases until the active principles of the therapeutant have been identified in the host, and this information is rarely available. Therefore, in most cases, where a mode of action has been suggested, it has been inferred from the behaviour of the compound in ancillary tests and does not rest on direct evidence. There appear to be only two cases where some specific identification of the active principle has been made. Brian and his collaborators [24] demonstrated biologically the presence of a compound with the same physiological properties as griseofulvin in the tops of plants, the roots of which had been treated with this antibiotic, and estimated the concentration of the active compound present. Dimond and Chapman [29] detected 2-norcamphane methanol by its characteristic smell in the foliage of plants whose roots had been treated with this compound.

This rather unsatisfactory state of affairs arises from the small quantities of the chemotherapeutants involved and the complicated nature of the biological system under examination. Some confusion is to be expected in the early stages of the work and one should bear in mind the part that pure conjecture plays in the interpretation of the results obtained. However, the fact that the interpretation of the results is open to criticism in no way invalidates the results themselves, and there appears to be no doubt that some diseases have been controlled by chemotherapeutic treatment.

Chemotherapeutic Treatment of Plant Diseases

Vascular diseases.—The vascular diseases of woody plants were among the first to be treated by internal medication and much information has been accumulated on their treatment. The damage associated with diseases of this type is frequently induced by toxins produced by the pathogen. The disease may, therefore, be arrested either by compounds that suppress the development of the pathogen, referred to as systemic fungicides, or by compounds which prevent the formation of the toxin or neutralize it when it has been formed. Compounds have been selected on their supposed ability to perform either or both these functions.

Bleeding canker of maple and other hardwoods (caused by *Phytophthora cactorum*) and Dutch elm disease are diseases in which the host symptoms are largely induced by the presence of toxins produced by

the pathogen. Both fungi produce in culture certain toxins that induce symptoms of the disease in the cut stems of the usual hosts and in unrelated species [8, 16]. The ability to cause wilting in cut stems has been used as the basis of a bio-assay method for determining the presence of the toxin. The test plants commonly used are either cut shoots of the host or a young tomato-plant cut off just above the roots [8, 11, 30]. These methods of assay allow *in vitro* studies on the physiology of toxin formation and the screening of compounds that may be of value in antidoting the toxins within the plant.

Using this type of assay, Howard [8] demonstrated *in vitro* that the dye Helione Orange, the active principle of which is probably diaminoazobenzene dihydrochloride, would inactivate the toxin of *P. cactorum*. He was further able to show that it was possible to reduce disease markedly in maple, beech, and two species of elm naturally infected with *P. cactorum* with injections of the same compound [8, 7]. Helione Orange has also been reported to inactivate the toxin formed by *C. ulmi* [16], but in field trials when used alone it appears to have little effect on the development of the disease though addition of the dye is reported to increase the efficiency of other treatments [13]. Horsfall and Zentmyer [16] have noted some organic compounds which will neutralize the toxin of *C. ulmi*, and also that produced by a Verticillium, which causes wilt in egg-plant; these are 8-hydroxyquinoline sulphate, diaminoazobenzene dihydrochloride, urea, malachite green, and probably ammonia. These workers suggest that the ability to neutralize the toxins may be related to the presence of basic nitrogen. In trials with infected plants, 8-hydroxyquinoline sulphate reduced the effect of both diseases.

Feldman, Caroselli, and Howard have studied the effect of acidity on the formation of toxin by *C. ulmi*. They noted that the toxin was destroyed by alkaline conditions when tested *in vitro* [30], and they further showed that the pH of the outer xylem of potted elm seedlings was influenced by soil acidity. When the pH of the potting soil was raised from 5·5 to 7·2–7·4 with lime, the pH of the outer xylem reached 6·9 in the roots and 7·2 in the stems within 7 days, and then fell rapidly to levels below that recorded for the unlimed soils. Seedlings growing in both limed and unlimed soils were inoculated with *C. ulmi* and after 21 days the latter all showed symptoms of wilt while the former appeared completely healthy. The seedlings in the limed soils were inoculated a second time 25 days after the first inoculation and 40 per cent. developed disease, showing that liming conferred little permanent protection [12].

Caroselli and Feldman used lime as the basis of a commercial formulation that has been used for treating trees in the field. It is usually injected into the soil surrounding the tree and, if applied before inoculation, it arrests the disease in 70 per cent. of cases for at least 2 years. When trees are treated after the symptoms have become visible, success depends on the extent to which the disease has spread through the tree: where less than 5 per cent. of the crown shows symptoms at the time of treatment the mortality may be reduced to 40 per cent. as compared with 79 per cent. when more than 5 per cent. of the crown is involved [9]. The infected and treated trees formed a broad annual ring that cut off

the discoloured infected tissue, but the pathogen remained alive within this circumscribed area and could be recovered in culture after 3 years. Further, a deep wound would, in some cases, release the pathogen, which would then reinfect the tree [9].

Besides the compounds selected on their ability to neutralize toxins, others have been found to reduce vascular diseases of trees in the field, and many of these have been shown to be fungicides. The following have been found effective in reducing Dutch elm disease when introduced into the elm: 8-hydroxyquinoline benzoate, quinone, hydroquinone, *p*-nitrophenol, benzoic acid, disodium ethylene bisdithiocarbamate (Dithane) [16]. Of these 8-hydroxyquinoline benzoate has been recommended for use in the field and its application has been described in some detail [11]. The effect of this compound is ephemeral, and it is probably best used as a preventive measure before infection.

Reverting to the reduction of the Verticillium disease of egg-plant with 8-hydroxyquinoline sulphate, this compound has been reported to reduce Verticillium wilt of maple [15]. It has also been reported that the American elm can be immunized against infection by *Verticillium albo-atrum* by injection, shortly before inoculation, with mycelial extract of the pathogen and with the staled medium in which it has been growing [14]. This effect does not appear to have been investigated further.

Whilst most of the early work on the chemotherapeutic treatment of vascular diseases concerned the control of economic diseases of trees, more recent attention has been directed to the vascular diseases of herbaceous and annual plants. These have been found convenient for the rapid testing of compounds, and in some cases the effects have been sufficiently striking to justify field trials. The diseases so far investigated are Fusarium wilts of tomato and carnation, bacterial blight of bean, and red core of strawberry.

The wilt of tomato caused by *Fusarium lycopersici* has been used extensively as a test for potential chemotherapeutants. Tomato-plants are raised in sand with a standard nutrient solution to which the chemical under test can be added as required. After treatment the young plants are dug up, and the roots are damaged and immersed in a strong spore-suspension of the pathogen; they are then re-potted and allowed to grow on without further fungicidal treatment. The extent of disease in these infected plants is assessed on an arbitrary basis taking account of the discoloration of the foliage, wilting, and the vascular discoloration in the petioles and stem [31].

Recent observations by Keyworth and Dimond [38] have shown that the development of Fusarium wilt in these conditions is profoundly affected by injury to the roots of the plants prior to inoculation. Substantial reductions in disease ratings can be obtained by any of the following treatments which cause injury to the roots: mechanical damage, hot-water treatment, and treatment with chemicals which are unlikely to be translocated, such as hydrogen peroxide and a number of inorganic salts. It is, therefore, impossible to decide whether the compounds which have been reported as reducing disease in this test [1, 29, 32] owe

their success to a specific effect on the disease or to a general ability to cause sub-lethal root damage.

Fusarium wilt of carnation, caused by *F. dianthi*, has also been strikingly reduced by most of the compounds which have proved effective against *F. lycopersici* [5, 29, 33, 34], but it should be borne in mind that the root-damage effect may also apply to this disease; 4-chloro-3-5-dimethylphenoxyethanol, 2-norcamphane methanol, and 8-hydroxyquinoline sulphate were all highly effective in reducing the disease both in the laboratory trials and in the greenhouse; 4-chloro-3-5-dimethylphenoxyethanol induced a slight increase in the number of active growing points, but had no ill effects on the leaves, and the smell of the 2-norcamphane methanol was not carried into the flower.

Red core, or red stele, of strawberry, caused by *Phytophthora fragariae*, has also shown signs of yielding to chemotherapeutic treatment. Plants grown in sand treated with Dithane D 14 (a disodium ethylene bisdithiocarbamate preparation) before inoculation have remained healthy for 2 months, whilst the untreated controls showed 90 per cent. disease; further treatment of infected soil has largely prevented the infection of new plants and prevented the spread of the disease into adjacent uninfected soil [34].

In the field trials mentioned above, the chemotherapeutant was added directly to infected soils, and the question arises whether the compound was acting inside the host or merely as a soil sterilizer. There is probably no simple answer to this question, and both effects may play their part, but in each case it has been demonstrated that the compound can enter the host and provide some protection after the source of supply has been removed.

Bacterial blight of the red kidney-bean, caused by systemic infections of *Xanthomonas phaseoli*, has also been used to investigate the chemotherapeutic properties of compounds [17]. The plants were raised in sand and the stems were inoculated by stabbing. The chemical under investigation was applied on the 9 days following inoculation and the disease was assessed 2 weeks after inoculation. Compounds reported as reducing the disease in this test are salicylic acid, acetyl salicylic acid, 8-hydroxyquinoline salicylate, 2(4-morpholinyl) ethylphenyl ketone, benzoic acid, ethylene urea, 2(1-ethylamyl)-2-imidazoline polyglycol, sorbic acid, and benzoyl methylthiocyanate [1, 18].

Leaf diseases.—Experimental treatments with compounds that become systemically distributed within the plant have shown that some of them can reduce the intensity of a variety of leaf diseases. The diseases were usually selected for the ease with which they could be handled in the laboratory, and the compounds tested were chosen because of their action on the pathogens.

Early blight of tomato caused by *Alternaria solani* is much used in the laboratory assay of protectant fungicides, and the intensity of the disease has also been reduced by systemic fungicides. The injection of a leaf with certain 4-nitrosopyrazoles markedly reduced the disease on other leaves of the same plant. The effect of these compounds was to reduce the speed with which the lesions grew rather than their actual number

[23]. The 4-nitrosopyrazoles are also highly effective protectant fungicides.

Alternaria leaf spot of tomato has also been markedly reduced when the roots of the plants were treated with griseofulvin, an antibiotic produced by *Penicillium nigricans* and *P. griseofulvum* [24]. This compound has also substantially reduced the effect of *Botrytis cinerea* on lettuce. At least 60 per cent. of the infected lettuce-plants were free from infection at the end of the trial as compared with 100 per cent. infection recorded in the untreated plants [24]. The work on griseofulvin is of particular interest because the characteristic curling effect that the compound has on the germ-tubes of certain species has provided a very sensitive means of detecting the systemic distribution of this compound within the host [24]. Griseofulvin is highly toxic to some fungi *in vitro*.

Another antibiotic, which is found in the filtrate of old cultures of *Cephalothecium* sp., has been reported as highly toxic to *Piricularia oryzae*, the pathogen causing blast of rice, and it is claimed that immersion of the roots of rice seedlings in this diluted filtrate does no damage to the host, but will reduce the number of leaf-spots produced by the pathogen [27].

Chocolate spot of broad-beans caused by *Botrytis fabae* and *B. cinerea* has been used to demonstrate the systemic fungicidal effect of various compounds, particularly a series of phenoxy acids [25, 26]. In most of the trials the compounds were applied to the roots and the disease assessed in the leaves, but it was also shown that the compounds were effective and mobile when injected into the stems, and when sprayed on to the leaves. In this series of experiments the phenoxy acids were investigated because they were known to be readily mobile within the plant, and parallel studies had shown that certain members of the group were fungicidal and did not induce undesirable growth effects [35–37]. This combination of properties appeared to offer a reasonable chance of finding an effective systemic fungicide and to some extent these hopes were realized. Three of the acids tested, 2-4-6-trichlorophenoxyacetic, pentachlorophenoxyacetic, and pentachlorophenoxy*iso*butyric acids, all reduced the disease significantly by about 30–40 per cent. in the laboratory trials. These acids remained active for some weeks in potting soil and have shown a marked effect in limited field trials. Other organic compounds have been tested against the chocolate spot of bean. None has produced a striking reduction in the disease, but it is noteworthy that many of the compounds reported as effective in controlling other diseases will also significantly reduce chocolate spot. These compounds include the following: 1 phenyl-3:5-dimethy-4-nitrosopyrazole [26], 8-hydroxyquinoline benzoate, 8-hydroxyquinoline sulphate, the active constituent of Helione Orange, and salicylic acid [25]. It is suggested that these compounds behave as systemic fungicides against chocolate spot of bean.

Seed treatment.—An interesting phase in the study of systemic fungicides has been the use of a chemical as a prolonged seed-steep to eliminate internal infections of *Asochyta pisi* [28]. Such a compound is the antibiotic XG derived from an organism closely related to *Bacillus*

subtilis; 18-hours' steeping of seed in a solution containing 25 p.p.m. of this compound will practically eliminate *A. pisi* infections beneath the seed-coat without reducing the viability of the seed. XG will inhibit the growth of *A. pisi* at a concentration of 2 p.p.m., and an exposure of 12 hrs. to 100 p.p.m. of XG will kill the spores of the fungus.

Discussion

In the foregoing sections an attempt has been made to outline the present work on chemotherapy, to indicate the value of this approach to the control of plant diseases, and to assess the success obtained. The evidence leaves little doubt that diseases can be controlled by compounds translocated systemically through the host, and that there are a number of chemicals that can operate in this way. The success of a systemically distributed compound will depend not only on its inherent ability to check the disease, whether it is acting primarily on the pathogen or the toxins produced by it, or on the host, but also on the readiness with which it is absorbed and translocated to the site of action, and on the extent to which it can be tolerated by the host. Thus a weak fungicide that is readily mobile, stable within the host tissues, and not phytotoxic, is likely to prove a better systemic fungicide than a compound which is far more lethal to the pathogen, but lacking one or more of the additional requirements. The less specific protection provided as a secondary result of root damage which has been noted above can fairly be considered a variation of the main theme since the external treatment has provided protection against the disease at some distance from the point of application.

One of the major difficulties in the study of chemotherapeutants is the lack of fundamental knowledge on which to base the choice of likely compounds. With the exception of a limited number of compounds, there is no information either on the translocation of organic molecules within the higher plants or on the basis of fungicidal activity. In these circumstances the choice of potential systemic fungicides has frequently been a matter of chance. On the other hand, the examination of the fungicidal activity of compounds known to be translocated within the host provides a logical approach to the problem and has, in fact, yielded some interesting results [26]. For compounds selected as antidotes to toxins, the toxin provides an obvious starting-point for research and, if the nature of the toxin is known, it should be possible to select chemicals that will neutralize its effects, provided that these can be transported to the site of the disease. Further, when using compounds that simply inactivate toxins it must be remembered that the pathogen remains alive and active, and thus it might be necessary to maintain continuous supplies of the inactivator to suppress the disease. However, the observations on Dutch elm disease [9] suggest that this will not apply invariably and that a treatment might be adequate if it checked the disease for a period long enough for the host to occlude the pathogen.

Despite the difficulties involved and the relatively short time during which the subject has been studied, some success in the field has been obtained by chemotherapy in the control of Dutch elm disease, and

possibly also of Fusarium wilt of carnations and strawberry red core, all of which do not respond to conventional methods of control. These successes illlustrate the possibilities in the control of plant diseases opened up by these methods.

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GROWTH OF THE PEDIGREE AYRSHIRE CATTLE POPULATION IN GREAT BRITAIN

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IN the realm of live-stock improvement emphasis is receding steadily from the small unit of the single individual and the single herd and is turning to the larger units of regional groups within breeds of live-stock and to breeds, or even species, as a whole. It follows the statistical nature of heredity that, in general, the larger the unit of material (herd, regional group, population, &c.) the more closely will it conform both under static and under changing conditions to patterns predictable by statistical techniques. In order to formulate breeding plans, it is, however, first necessary to know what is the present structure of the population to be planned for, and how this structure has changed over a period of time. The account which follows is intended to contribute information on some aspects of the dynamics of the Ayrshire cattle population in Great Britain.

Early history.—When in 1811 Aiton [1] published his *General View of the County of Ayr*, he noted an 'Adage of the district of unknown antiquity: "Kyle for a Man, Carrick for a Cow, Cunningham for Butter and Cheese, and Galloway for Woo".' From this it would appear that the Cunningham district of Ayrshire had for long been renowned for its milk cattle, though it seems reasonable to suppose from the evidence of other authorities, quoted by Prentice [2], that this renown does not date back much farther than the end of the seventeenth century. Douglas [3], Smith [4], and Prentice [2] give admirable summaries of the breed history, and the account of Farrel [5] published in 1876, though in the light of subsequent writings more speculative in its conclusions, is of interest too. The Highland and Agricultural Society of Scotland offered prizes for bulls and heifers in the Kyle district of Ayrshire in 1814, and Smith [4] states that this is the first public reference to the breed by the name of Ayrshire. The Herd Book Society was founded in 1877 and its first volume was published in 1878.

The Ayrshire breed spread more slowly at first than had been expected by Aiton [1], but Low [6] writing in 1852 states that '. . . it now forms the prevailing stock (apart from Ayrshire) of Renfrew, Dumbarton, Stirling, and Lanark, and it has extended into the shires of Dumfries, Wigtown, and Kirkcudbright. It has been carried into England, where, however, it has never arrived at the estimation which it possesses in its native pastures . . . those (cows) of Ayrshire appear to have the peculiarity of tending too much to fatten with a corresponding diminution of milk when they are transported to richer herbage than is natural to them.' The breed had, however, even then been exported to the U.S.A., Canada,

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and Finland, and, subsequently to Low's report, it went to Sweden, Norway, New Zealand, Australia, and many other parts of the world [4]. Ayrshires outside Britain appear to have been particularly successful, while retaining their breed identity, in the U.S.A., in Canada, and in Finland.

It is with the period after the establishment of the Ayrshire Herd Book in 1878 that this study deals, but it is in the light of early breed history that subsequent events may best be appreciated.

Material and methods.—The material consists of registrations of pedigree males and females, and of grade females taken from the herd-books of the Ayrshire Cattle Herd Book Society. The latest volume available when this study began was vol. 69, 1946. Although details of regulations for entry into the herd-book, and particularly into the appendixes, have altered slightly with the passage of the years, the general pattern of the information given in respect of each animal has remained much the same over the whole period of publication of the book. Registrations have been taken as indicative of population trends in the pedigree Ayrshire population. If the number of annual registrations is plotted against the appropriate years, the resulting frequency polygon shows the rate of increase and fluctuations in the size of the pedigree population (as represented by annual registrations). Examination of Fig. 5 (p. 201) will show that the six years (1879, 1896, 1906, 1927, 1943, and 1946) chosen in the following pages to study the growth of the registered Ayrshire population are fairly representative of the various periods of numerical growth. Vol. 1, 1878, had to be excluded from consideration in this study since it contains the entries of foundation animals both dead and alive, and of all ages. Age at registration has varied from period to period. The majority of animals are now registered within a few weeks of birth, but before 1914 the registrations were about equally divided among all ages up to about 4 years old. Where these differences in registration habits are likely to detract from the value of registrations as an indication of population numbers and trends, this will be stated in the appropriate section of this study.

Herds are defined (except where otherwise stated) as consisting of animals registered by owners or breeders of Ayrshire cattle who register at least one female in any volume of the herd-book under consideration. Herd sizes were calculated on the number of females registered by herd owners, who were not necessarily the mating breeders.

Although absolute accuracy of herd-book information, and particularly of pedigrees, cannot be assumed, the herd-book entries are considered a sufficiently reliable source of information for the purpose in hand, since it is the actual existence of animals, rather than their particular ancestry, that is of primary interest here.

Geographical distribution.—The location of pedigree Ayrshire herds at various periods will be found in Figs. 1–4. Each dot on the maps represents one herd irrespective of size; in view of the large number of herds involved, particularly in later years, it is not practicable to make a herd-size distinction.

In 1879, the year after the inception of the herd-book, it can be seen

that the majority of the herds are clustered in Ayrshire; most of the remaining herds are found in the adjoining counties of Lanark, Renfrew, and Dumfries. It is of interest that no females were registered from the neighbouring counties of Wigtown and Kirkcudbright—in fact if the 'geographical distribution' of the 165 members of the Herd Book Society

FIG. 1. Distribution of herds registering Ayrshire females in 1879. (Each dot represents one herd—irrespective of size.)

in 1879 is examined, it is found that the native area and the large milk-consuming area of Glasgow and neighbourhood accounted for 90 per cent. of those interested at that time in pedigree Ayrshire cattle.

The distribution of the registered Ayrshire population had not changed much even at the turn of the century, but by 1927 the south-west of Scotland (excluding Ayrshire) had more herds of registered Ayrshires than the county of Ayr itself. Although only 39 herd owners in England and Wales in 1927 registered Ayrshire females, it can be seen that the distribution of these herds had more or less set the broad pattern of the distribution of the breed in later years. This is similar to the findings of Donald [7] with Red Poll cattle.

By 1946 there are seen to be pedigree Ayrshire herds in practically all districts normally associated with dairy cattle in England, Wales, and

Scotland, even though relative to other breeds they are more numerous in some districts than in others.

Numerical growth and features of the increase.—Pearl [8] has shown that the growth of populations in relation to their environment—like the growth of individual organisms (Brody [9])—follows a trend which can be described by an S-shaped curve. In the pedigree Ayrshire cattle

FIG. 2. Distribution of herds registering Ayrshire females in 1906.

population there was a steady increase in the number of registrations from about 1906 to 1942; rate of increase then became very rapid. This is shown by Fig. 5. The marked irregularity in the number of registrations of females at the time of the 1914–18 war is due primarily to a change in registration procedure which was abandoned again in 1920. Fluctuations in the number of registrations between 1916 and 1922 do not therefore imply corresponding fluctuations in actual population numbers. If the data for Fig. 5 are plotted on arith-log graph-paper and a straight line fitted by eye, it is found that the rate of increase is roughly exponential. If it continued, the annual number of registrations would be about 50,000 by 1960. Such extrapolation, however, presupposes a continuance of the conditions that governed the growth of the population

up to the last census. Obviously, forces must come into play sooner or later which will check the rate of expansion and ultimately limit the size of the population. From the available evidence it may be said,

FIG. 3. Distribution of herds registering Ayrshire females in 1927.

however, that this stage in the growth 'curve' of the pedigree Ayrshire cattle population in Great Britain had not been reached in 1946.

When the data are examined by regions as in Table 1, it becomes clear that breed growth has not been uniform.

It can now be seen that up to 1906 the numerical expansion of the

FIG. 4. Distribution of herds registering Ayrshire females in 1946.

TABLE 1. *Numerical Distribution of Pedigree Ayrshire Cattle according to Region in Six Representative Years*

(Herds are defined as registering at least 1♀; ♀♀ include appendix animals)

Region	1879 number of		1896 number of		1906 number of		1927 number of		1943 number of		1946 number of	
	herds	*reg. ♀♀*	*herds*	*reg. ♀♀*	*herds*	*reg. ♀♀*	*herds*	*reg. ♀♀*	*herds*	*reg. ♀♀*	*herds*	*reg. ♀♀*
Ayrshire . .	28	73	62	476	88	684	134	1,621	198	3,410	299	4,591
SW. Scotland (excl. Ayr) . . .	15	78	42	468	45	370	231	3,024	321	5,703	538	8,982
Rest of Scotland .	6	16	10	38	11	63	39	278	83	1,314	214	2,871
England, Wales, and Ireland . .	2	3	6	28	1	4	44	420	309	4,066	897	8,226
Total . .	51	170	120	1,010	145	1,121	448	5,343	911	14,493	1,948	24,670

breed was confined largely to the county of Ayr itself. Between 1906 and 1927 both the absolute and the proportionate increase in numbers of herds and of females was greatest in the area surrounding the county of Ayr, i.e. the region termed 'SW. Scotland' in Table 1 (this region includes the counties of Bute, Dumfries, Kirkcudbright, Lanark, Renfrew, and Wigtown). In the period 1927–43 the greatest proportional

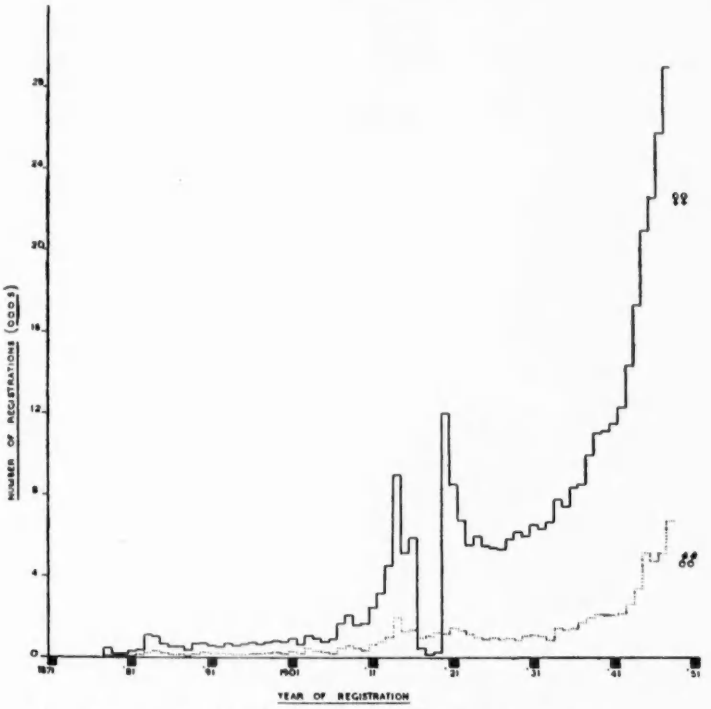

FIG. 5. Annual registrations of males and females in the herd-book (excluding appendixes since vol. 1, 1878.)

increase in herds and in females took place in England, and between 1943 and 1946 again in England, but about equally in the area termed the 'Rest of Scotland'. As during each of the periods chosen since 1906 the rate of growth in number of herds (except SW. Scotland between 1927–43) and in number of females has been greater than in the preceding period, each of the four regions is still in the 'expanding' stage of the population-growth curve. This is not to say that the growth-curve looks the same for each of the regions, or that expansion will continue for the same period in all of them.

One of the features of breed expansion—particularly when this takes the breed into districts where it was not previously kept—will be the

establishment of a large number of new herds which may or may not differ in size from their older contemporaries. The importance of herd-size in live-stock improvement has been stressed by Donald and Itriby [10]: chance variations in gene-frequency are likely to be more violent and less predictable in small herds than in large ones [11]. It is worth while, therefore, to examine briefly the effect on herd-size of the Ayrshire-breed expansion. When most of the females are registered during their first year of life, an estimate of herd-size may be obtained by multiplying the number of females registered per herd by 5 [10]; this procedure would thus give an underestimate of herd-size for the first three volumes (2, 19, and 29) but not for the later three volumes (50, 66, and 69) here studied (see *Material and Methods*).

Up to 1943 the number of Ayrshire females registered increased at a greater rate than the number of herds, with a consequent rise in average herd-size (Table 2); between 1943 and 1946, however, the rate of increase in the number of herds exceeded that of females with the result that the average number of females registered per herd dropped from 15·9 to 12·7. It is not, of course, possible to say without further investigation what proportion of the registrations made in 1946 was absorbed by herds already in existence for a number of years, and what proportion can be ascribed to newly established herds. It seems reasonable to suppose, however, that under economic conditions favourable to the dairying industry, the well-established herds would at least maintain, if not increase, their size (apart from those which 'die' in the ordinary course of events). This assumption is to some extent borne out by examining the average number of females registered per herd on a regional basis; thus, Table 2 shows that the decline in the average number of females registered per herd was proportionately much smaller in the county of Ayr, an area with a large proportion of long-established herds (from 17·2 to 15·4, i.e. a reduction of slightly over 10 per cent.), than in England, Wales, and Ireland with relatively more newly established herds (from 13·2 to 9·2, i.e. a decline of over 30 per cent.).

TABLE 2. *Average Number of Females registered per Herd in Six Representative Years, according to Region*

Region	*1879*	*1896*	*1906*	*1927*	*1943*	*1946*
Ayrshire . . .	2·6	7·7	7·8	12·1	17·2	15·4
SW. Scotland (excl. Ayr)	5·2	11·1	8·2	13·1	17·8	16·7
Rest of Scotland . .	2·7	3·8	5·7	7·1	15·8	13·4
England, Wales, & Ireland	1·5	4·7	4·0	9·5	13·2	9·2
Great Britain—Average .	3·3	8·4	7·7	11·9	15·9	12·7

It will be noted, moreover, that of the four regions shown in Table 2, only England, Wales, and Ireland—the region with the largest absolute and proportionate increase in the number of herds since 1927 (see Table 1)—fails to show an increase in the average number of females registered per herd in 1946 compared with 1927. It would thus appear

that the decrease in the average number of females per herd between 1943 and 1946 is due primarily to the establishment of relatively large numbers of new herds that are smaller than their older contemporaries. This may be further substantiated if it can be assumed that herds start with small numbers which they build up gradually. Table 3 shows the change in frequency of small and of large herds over a period of time.

TABLE 3. *Average Number of Females registered per Herd in Large and Small Herds in Six Representative Years*

Year of Registration (H.-B. volume)	*Herds registering* < 10♀♀		*Herds registering* > 10♀♀	
	No. of herds	*Av. No. of ♀♀ reg. per herd*	*No. of herds*	*Av. No. of ♀♀ reg. per herd*
1879 (vol. 2)	50	2·6	1	(40)
1896 (,, 19)	83	4·2	37	17·9
1906 (,, 29)	104	4·6	41	15·7
1927 (,, 50)	229	5·6	219	18·6
1943 (,, 66)	401	4·9	510	24·6
1946 (,, 69)	1,117	4·2	831	24·1

Whilst average size of herds registering less than ten females per herd has been falling since 1927, that of herds registering more than ten females per herd has been rising (the slight decrease between 1943 and 1946 is proportionately much smaller for the large than for the small herds).

It should be added that Donald and Itriby have shown that in 1939, over 75 per cent. of herds of all dairy breeds except Ayrshires (40 per cent.) fell within the limitation of a herd size of 1–20 cows. The data in this study show in respect of herd size for Ayrshires in 1927, 1943, and 1946 broad similiarity with that of the previous study made for 1939. In 1946, 22 per cent. of the herds registering Ayrshire females belonged to a size-class exceeding 100 females of all ages (registering >20 females), and both in 1943 and in 1946 about 60 per cent. of all the females registered came from such herds.

Regionalization of bull breeding.—A widening of the geographic distribution of a breed of live-stock may mark its entry into environments different from that of its native area and may involve the development of new breeding centres adapted for possibly new requirements. Especial interest centres therefore around those herds that make the greatest contribution to future generations of the breed, i.e. the herds breeding males, and more specifically those whose males become the sires of future generations of the pedigree population.

It has been shown [12] that in the Ayrshire breed there exists a division of function amongst herds. A large proportion of the pedigree Ayrshire population was shown to have been sired by bulls from a relatively small number of herds. Not all herds bred bulls, and only a few bred them in large numbers. In Table 4 it is shown that this specialization of function has a geographic aspect: the production of sires of pedigree

stock, particularly males, is concentrated in the native area of the breed, that is, Ayrshire and the adjoining counties of the south-west of Scotland. In this Table, columns 1 and 2 show the percentage distribution—according to regions—of the female and of the male registrations made in the herd-book in 1946; thus, in 1946, herds in Ayrshire registered 18·4 per cent. of all the females and 23·5 per cent. of all the males. Column 3 of Table 4 shows the percentage distribution of a sample of registered females arranged according to the regions where their sires originated, and column 4 uses the same classification for all the males registered in the 1946 herd-book; thus 41·9 per cent. of the females in the sample and 52·7 per cent. of all the males registered in that year were sired by bulls bred in Ayrshire, compared with less than half that number registered by herds in that county.

TABLE 4. *Distribution of Females and of Males registered in 1946, according to* (i) *Region of Registration;* (ii) *Region where the Sire originated*

	Distribution according to region of registration		*Distribution according to region of origin of sire*	
	1	*2*	*3*	*4*
Region	*% of all ♀♀ registered (excluding appendixes)*	*% of all ♂♂ registered in herds registering at least 1♀*	*% of ♀♀ in the sample*	*% of all ♂♂ in the herd-book*
Ayrshire	18·4	23·5	41·9	52·7
SW. Scotland (excl. Ayr) .	35·2	27·2	35·4	27·8
Rest of Scotland . . .	11·9	11·2	5·5	3·0
England, Wales, and Ireland .	34·5	38·1	17·2	16·5
Total number . . .	22,422	4,438	2,231	4,737

Table 4 shows that in 1946, 38·1 per cent. of bulls registered were bred in England, Wales, and Ireland, but 16·5 per cent. had sires bred there. It follows that the sires of the majority must have come from Scotland.

If all the males registered in the 1946 herd-book are classified according to the herds where their sires originated, it is found that bull-breeding herds in Ayrshire each supplied the sires of an average of 26·3 males registered in the herd-book, whereas each such herd in the south-west of Scotland (excluding Ayrshire) provided the sires of 9·6 males, herds from the 'Rest of Scotland' the sires of 4·2 males, and English, Welsh, and Irish herds the sires of 5·3 registered males. There is considerable variation within regions in the number of registered males that may be traced through their sires to a particular herd. In Ayrshire, some herds were in 1946 represented by only one registered male, and two herds each by more than 300 males. It may be concluded, however, that on average the effectiveness of selection in herds in Ayrshire which supply bulls to other pedigree breeders is likely to be significant for the whole breed.

Discussion

Large expansion such as that of the Ayrshire cattle population over the past fifty years or so has at least four concomitants of interest to the geneticist:

1. Rate of increase, which influences the amount of selection that can be practised;
2. new environments and possibly geographical isolation, which may lead eventually to the development of local breed types;
3. effective size of breeding population, which will determine what changes in gene-frequency might be expected from varying degrees of selection pressure, or from random fluctuations; and
4. wider opportunities for cross-breeding.

Dawson and Graves [13], using a hypothetical case of a herd of 1,000 milking cows, assuming no culling for low producers and a 12 per cent. annual wastage-rate, calculated that the herd would double its number in seven years. Donald [14] showed that a breed would double its number of registrations in seven or eight years at a steady rate of increase of 10 per cent. per annum. The latest Ayrshire herd-book on hand (vol. 71—the second volume published in 1947) shows that Ayrshire female registrations have doubled within roughly five years. The percentage increases from 1943 to 1947 were 20, 21, 8, 14, and 13. The 12 per cent. annual wastage-rate assumed by Dawson and Graves is lower than the investigations of Pettit [15] and Ward [16] show. How the increase in the number of Ayrshire registrations was achieved remains therefore to be investigated. Preliminary results indicate that it was not brought about by keeping cows to a greater age than formerly. Calving for the first time at an earlier age and a reduced calving interval appear to have played some part. It seems probable that there cannot have been much scope for culling of low producers.

It was shown earlier that the geographic distribution of the pedigree Ayrshire population in Great Britain has considerably widened, and that almost twice as many Ayrshire females were in 1946 registered in England, Wales, and Ireland than in their native area—the county of Ayr. This raises the possibility of geographical isolation of breeding groups and the development of local breed-types differing in gene-frequencies from the population as a whole, although this in turn will depend on the effective size of the local population, provided isolation is genetic. Wright [17, 18] has pointed out that, under certain conditions, local differentiation presents more favourable conditions for an effective process of selection and for adaptive advance of the population than is possible under purely panmictic conditions. Breed structure and movement of breeding stock bearing on this problem will be discussed in future papers, but the information already to hand (Table 4) shows that there can be little genetic isolation of regions in the registered Ayrshire population, when (*a*) more than half the sires of registered males come from Ayrshire itself, and (*b*) all regions except Ayrshire and the south-west of Scotland register considerably more males and females than could

be the offspring of bulls bred in the same region—assuming, on average, the same number of offspring per bull, whatever his region of origin. This does not, of course, preclude the possibility of genetic isolation of individual herds within regions. Within the limitation of size of most herds, however, differentiation is more likely to be non-adaptive due to random drift in gene-frequencies than in larger isolated units where selection has a better chance of being effective.

Widening geographic distribution of the Ayrshire breed has also brought it into closer proximity with an increased number of animals of other breeds, thus widening the opportunities for cross-breeding. The bull-licensing figures in Table 5 show that although Ayrshires have become increasingly important as a competitor to other dairy breeds in England and Wales (there has been no increase in the total number of bulls of all breeds licensed between 1936 and 1948), the other dairy breeds are not as yet of any great numerical importance in Scotland relative to the Ayrshire.

TABLE 5. *Bulls Licensed in Great Britain for Five Breeds of Cattle*

*Country and year**	*Ayrshires*	*British Friesians*	*Guernseys*	*Jerseys*	*Shorthorns†*
England and Wales					
1936–7	445	2,502	1,882	613	24,600
1942–3	1,101	9,096	1,111	527	21,268
1948–9	3,154	9,099	1,567	909	11,287
Scotland					
1936	3,877	274	12	21	–
1942	3,930	274	6	12	64
1948	5,713	389	11	28	54

* Licensing years in Scotland run from January 1 to December 31; for England and Wales from March 31 to March 31 of the following year.

† Shorthorns: Figures for Scotland are for Dairy Shorthorns only; for England and Wales all Shorthorns are included: the 11,287 licences issued in 1948–9 consisted of 197 Beef, 3,169 Dairy, and 7,921 General Licences.

Increased opportunities for cross-breeding may imply that genes from other breeds may enter the Ayrshire breed by the process of grading-up to a greater extent than in former times, when the foundation stock in a grading-up scheme was more likely to be non-registered Ayrshires. It may also imply the use of bulls of other breeds on Ayrshire cows with the intention of steering the male calves. Data have, however, not been collected to ascertain the extent of, or the result of, a considered policy of cross-breeding with Ayrshire cattle.

Translated into more practical terms the concomitants of breed expansion of interest to the geneticist are of importance to the breeder also. It poses the questions whether another breed is in fact required in districts where it was not previously found; whether in fact the rate of increase is desirable; whether a breed-structure evolved for a localized breed is a good basis for a breed with a greatly widened distribution.

Summary

The Ayrshire breed of cattle developed in the Cunningham district of Ayrshire in the latter part of the eighteenth and early nineteenth century. It spread, slowly at first, to the surrounding counties, and large-scale movement of the breed into England is of at most twenty years' duration.

Between 1879 and 1946 the number of herds of registered Ayrshire females increased from 51 to 1,948, and the number of females registered from 170 to 24,670. The rate of increase in numbers is roughly exponential when judged by a line fitted by eye. Although the rate of increase of the pedigree Ayrshire population has not been the same in all regions of Great Britain, that stage in an S-shaped growth-curve (to which population growth may be likened) where the rate of expansion begins to decline, had not been reached in 1946 in any of the regions considered in this study; this despite a doubling in the number of female registrations within a five-year period (1943–7).

Up to 1943, the average number of females registered per herd increased in all regions, but between 1943 and 1946 the number of herds increased at a greater rate than the number of females, with a consequent drop in the average number of females registered per herd. It is shown, however, that this drop, which is proportionately much greater in England than in any region in Scotland, is due primarily to the establishment of a relatively large number of new herds which are smaller than their older contemporaries. Also, since 1927, the number of females registered per herd has increased in herds registering more than ten females per herd, but it has decreased in those registering less.

Bull-breeding is still carried on to a greater degree in the native area of the breed than in other regions where Ayrshires are registered. Thus, while 18 per cent. of all females in 1946 were registered by herds in the county of Ayr, 24 per cent. of the males were registered by herds in Ayrshire, and 42 per cent. of a sample of females and 53 per cent. of all the males registered in 1946 had sires bred in Ayrshire.

Some of the genetic implications of pedigree-Ayrshire breed-expansion are discussed.

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THE EFFECT OF A SUB-CLINICAL WORM-BURDEN ON THE LIVE-WEIGHT GAIN OF SHEEP AT PASTURE

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THE feeding-value of a pasture is frequently determined by using sheep as the grazing unit and following the live-weight changes as an index of production. Much work has been carried out indicating that heavy infestations of nematodes parasitic in the alimentary tract of sheep adversely affect the ability to gain weight. Andrews, Kauffman, and Davis [1], working with lambs heavily infested with *Trichostrongylus colubriformis*, state that 'the energy metabolism of all infected lambs was increased, as was also the number of pounds of feed necessary to produce 100 lb. of gain'. Willman, Baker, and Embry [2] conclude that 'failure of lambs to make satisfactory rates of gain is due, in many cases, to heavy infections of internal parasites'. Even light infestations have been shown to produce a significant effect upon the nutrition of lambs. Andrews [3], using lambs infested with *Cooperia curticei*, showed that 'infestations with a relatively non-pathogenic nematode decrease the ability of the infested lambs to convert their feed into gain in weight, even when these lambs are in excellent condition and show no clinical symptoms of parasitic infestation'. Similarly Gordon [4], referring to Trichostrongyles, stated 'even moderate sub-clinical infestations cause a depression in appetite and adversely affect food utilization'.

Much of this work, however, has been based on comparisons between lambs dosed with infective larvae (usually of one species of nematode) and control lambs completely worm-free. The effect of worm-burden on sheep at pasture is not so clear, and a correlation of live-weight gain with size of worm-burden is far from being established. Fraser, Robertson, and Ritchie [5] state that 'there is a definitely significant correlation between the worm-burden and live-weight increase of grazing sheep' and refer to a positive correlation in this respect. In the same paper they consider that 'those lambs which are gaining weight most rapidly tend to contain the greatest number of worms'. They suggest that the most probable reason for this correlation would be that 'the most thriving lambs eat more grass and consequently ingest more larval worms'. Such conclusions do not necessarily mean that each lamb would not have maintained a still greater rate of live-weight gain if it had carried fewer worms. Robertson and Fraser [6] found that 'a mixed worm-burden of about 2,000 worms results in scouring and loss of condition, slight anaemia, and probably in decreased live-weight and carcass-weight in comparison with worm-free controls kept under the same environmental conditions'.

All the sheep normally used in grassland experiments are infested with worms to some extent and differences in the size of worm-burden between animals may be considerable. In feeding trials it is important

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to know the effect of such differences on the digestive economy, and to study the level below which the infestations become insignificant. The present paper deals with the results of an investigation into the effect of sub-clinical, mixed infestations on the live-weight gain of sheep.

Two main experiments were carried out.

Experiment 1. June 1950–October 1950

In the first experiment shearling sheep, Half-bred × Suffolk wethers, were used. They were divided into two groups (*A* and *B*) of 6 sheep each and during 122 days grazed on similar pasture at different levels of infection. The grazing area was divided into 4 paddocks of $\frac{1}{4}$ acre, and each group was allotted two of these paddocks. The latter were grazed alternately and both groups were moved simultaneously from one paddock to the other. All the sheep were fitted with leather harness and close-fitting, rubberized bags enabling the complete faecal output to be collected. This was done twice daily, at 10.00 hrs. and 17.00 hrs. (B.S.T.).

Initially the pasture was considered not to be infected since it had not been contaminated by sheep faeces for over 2 years. The collection of faeces by bagging the animals ensured that this condition could be maintained where desirable. The aim was to build up an infection on the paddocks grazed by Group *A* whilst keeping the others clean. Group *A* paddocks were therefore grazed before the experiment by 20 sheep for 3 days to establish an initial infection. At the same time Group *B* paddocks were cut to remove an equivalent amount of herbage. From the commencement the faeces collected from Group *A* were spread evenly over the paddocks grazed by that group. The faeces from Group *B* were not returned. Group *A* was thus subjected to a constant reinfection by the return of faeces, while Group *B* continued to graze clean pasture. In both *A* and *B* the faeces collected were weighed and sampled for egg-counting and daily dry-matter determinations. The latter were made by drying 500 gm. samples at 80° C. for 2 days. Egg-counting was carried out in duplicate by zinc sulphate flotation technique, as developed at the Parasitological Laboratories, Weybridge. The eggs were not differentiated, but the type of infestation can be judged from post-mortem worm-counts carried out on the abomasal and intestinal contents in December 1950 at the Ministry of Agriculture Veterinary Laboratory, Weybridge, by the kindness of Dr. E. L. Taylor. The chief species found, in order of prevalence, were: *Cooperia curticei*, *Trichostrongylus axei*, *Strongyloides papillosus*, *Ostertagia circumcincta*, *Trichostrongylus colubriformis*, *Nematodirus filicollis*.

The sheep were weighed between 10.00 and 11.00 hrs. (B.S.T.) on three or four successive days of each week and the mean of these results taken as the weight of the animal for that week. No weighings were carried out when the fleeces were wet, due to either rain or heavy dew. Periodically the animals were 'rested' for a few days. During these rest periods the collection bags were removed, but not the harness, and the sheep grazed on other 'clean' pastures. The duration of the experiment (122 days) necessitated special precautions against fly 'strikes', since the

constant wearing of bags tended to keep the sheeps' quarters rather soiled. Daily spraying with benzene hexachloride solution prevented any serious interference from this source.

Discussion of Results

The results of Experiment 1 are dealt with in two ways. First, the sheep are considered as two groups and the average live-weight gain of the groups and the average worm-burdens (as indicated by faecal egg-counts) are compared. Secondly, comparisons are made within each group.

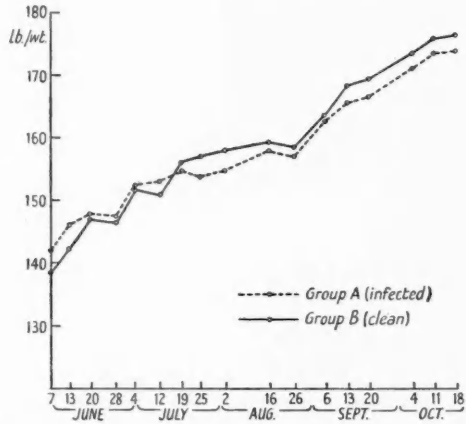

FIG. 1. Average live-weights of two groups of sheep at pasture.

(1) *Comparisons between groups.*—The average weekly live-weight data for each group are shown in Fig. 1 and tabulated (Table 1) to show the average live-weight gain for each group.

When the experiment started, Group *B* had a lower average live-weight and a higher average egg-count than Group *A*, both of which were reversed during the course of the trial. It will be seen that Group *B* gave an average gain of 39 lb. per sheep as against 33 lb. per sheep in Group *A*; a difference of nearly 20 per cent.

Egg-count data are given in Table 2 and in Figs. 2 and 3. Infestation rose rapidly to a peak in both groups at the end of June, and then declined sharply to a very low level. This sudden drop in the counts of all animals appeared to be an example of the 'self-cure' phenomenon discussed by Gordon [4]. Following this the increase was slightly more rapid in Group *A*, but the egg-count level in the two groups differed relatively little in this period, in spite of the different degree of infection to which the two groups were exposed.

Infestation therefore seemed to occur in two phases. Up to the time when the significant drop in egg-counts took place infestation was relatively high and the maximum difference appeared between the groups.

TABLE 1. *Average Live-weight Gains of Sheep, Groups A and B. June–Oct. 1950*

	Date	*Group A (on infected pasture)* L/wt. lb.	*Group B (on 'clean' pasture)* L/wt. lb.
Period 1	7/6	141·7	138·7
	13/6	145·8	142·2
	20/6	148·5	147·5
	28/6	147·3	146·5
	4/7	152·7	152·2
	12/7	152·8	150·7
	19/7	155·2	156·2
	25/7	153·8	157·2
	2/8	154·7	157·8
Period 2	16/8	158·5	158
	26/8	157	158·3
	6/9	163·3	163·5
	13/9	165·7	168·3
	20/9	166·5	169·5
	4/10	170·7	173·5
	11/10	173·7	176
	18/10	174·3	177·3
Average live-weight gain, lb. per sheep . .		33	39

TABLE 2. *Egg-count Data of Sheep, Groups A and B. June–Oct. 1950*

	Date	*Group A (on infected pasture)* e.p.g.	e.p.d.	*Group B (on 'clean' pasture)* e.p.g.	e.p.d
Period 1	8/6	62	101,370	163	379,464
	15/6	171	426,303	182	510,510
	21/6	281	714,583	300	966,300
	28/6	391	969,680	265	524,700
	3/7	367	1,161,188	170	533,970
	11/7	12	36,660	22	60,456
	15/7	20	54,040	17	60,214
	17/7	17	41,157	7	21,896
	24/7	23	51,129	10	24,970
	31/7	23	61,594	8	21,544
Period 2	24/8	86	175,182	34	108,188
	25/8	88	223,080	25	73,075
	5/9	53	137,906	12	35,676
	11/9	40	90,440	29	70,876
	18/9	12	32,928	15	38,985
	2/10	193	452,199	64	179,840
	11/10	63	148,869	58	149,872
	18/10	52	135,720	41	84,460

e.p.g.=eggs per gram; e.p.d.=eggs per day.

From then on infestation was low in both groups and the difference in levels correspondingly less.

The first period of 51 days (a period of sufficient length for the live-weights to be considered accurate) was one during which considerable

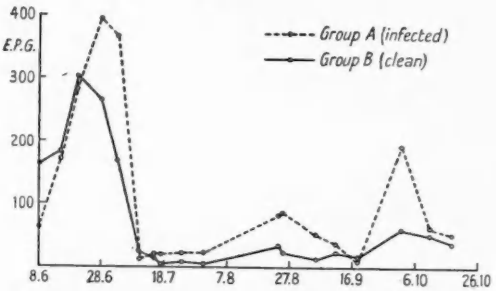

FIG. 2. Mean group egg-counts of groups A and B.

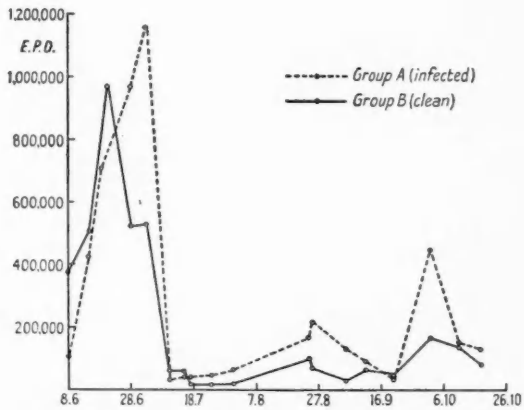

FIG. 3. Average egg-production per sheep per day.

differences in the live-weight gain of the two groups were shown. These differences appeared less over the whole period of 122 days, as would be expected from the smaller difference in infestation levels, as time went on.

(2) *Comparison within groups*.—Within each group considerable differences in the level of infestation and the rate of live-weight gain occurred with individual animals. The total live-weight gains in Period 1 (51 days) and the mean egg-count (derived from weekly egg-counts) for each sheep are shown in Table 3.

One animal, the smallest, in each group, showed a relatively low live-weight gain in spite of the small size of the egg-count. Apart from these two instances (sheep nos. 5 and 6), a negative correlation was traceable

between the live-weight gain and egg-count—whether expressed as eggs per gram (e.p.g.) or as eggs per day (e.p.d.)—of the sheep within each group. That this no longer held when the members of the two groups were regarded as a single unit of twelve animals indicates a superimposed environmental effect.

TABLE 3. *Average Live-weight Gain and Egg-count Data for each Sheep. June–Oct. 1950. Period 1.*

	Sheep No.	*L/wt. increase in lb.*	*Average e.p.g.*	*Average e.p.d.*
Group A	4	18	51	103,839
	10	16	115	164,242
	11	14	103	204,095
	6	12	40	105,908
	2	11	375	694,122
	1	9	450	696,117
		Av. 13·3	189	328,220
Group B	12	25	38	93,835
	8	20	150	244,779
	9	20	120	317,563
	3	20	125	257,512
	7	16	220	796,320
	5	15	75	180,919
		Av. 19·3	121	315,155

In Period 2 (Table 4) only relatively slight differences in egg-count were obtained and, although there was considerable variability in the live-weight gain within each group, no correlation was possible. However, even in Period 1, where a good correlation was experienced, the

TABLE 4. *Average Live-weight Gain and Egg-count Data for each Sheep. June–Oct. 1950. Period 2.*

	Sheep No.	*L/wt. increase in lb.*	*Average e.p.g.*	*Average e.p.d.*
Group A	11	23·2	33	86,787
	6	23·0	17	33,448
	10	22·3	130	334,696
	4	17·0	39	103,325
	1	16·7	20	39,124
	2	16·0	170	345,171
		19·3	68	157,092
Group B	8	23·7	52	121,570
	3	22·7	13	35,666
	7	20·3	55	95,116
	12	19·5	34	76,763
	9	17·5	17	33,793
	5	12·3	53	119,228
		19·3	38	80,356

differences in live-weight gain appeared large in proportion to the associated differences in egg-count.

The experiment suffered from two defects which may have been responsible to some extent for these large differences. First, the return of faeces to the pasture grazed by Group *A* may have created some difference in the sward, particularly as regards palatability. Sears, Goodall, and Newbold [7] state that although 'the quick response by the grass to the return of urine is reflected both in the yield and composition . . . the effect of the dung is clearly seen with its relatively slow build-up of the pasture sward'. Since there was no interference with the return of the urine, and as the effect of the return of faeces was unlikely to be large during the experiment, differences in the sward composition were probably very small. The palatability of those parts of the pasture contaminated by faeces would undoubtedly be reduced, and the dry-matter figures for faecal output indicated that there might have been a difference between the amounts eaten by the two groups. They could, however, equally well indicate a difference in the digestive efficiency of the two groups. In Period 1 the average dry-matter faecal output per sheep per day was 511 gm. for Group *A* and 570 gm. for Group *B*. The equivalent figures for Period 2 were 518 and 579 gm. respectively. Thus, if faecal output is in this instance a reflection of feed-intake, the difference between the amounts eaten by the two groups was much the same in Period 1, when there was a 20 per cent. difference in live-weight gain, and Period 2, when the increase was the same.

Secondly, the two groups being exposed to different degrees of infection on the pasture, the animals in Group *A* would have been ingesting many more infective larvae per unit of herbage-intake than those in Group *B*. Possibly this had an adverse effect on the sheep, independent of the effect of those worms which succeeded in establishing themselves.

Experiment 2 was designed to overcome these defects and to obtain a wider range of levels of infestation. The latter might then indicate the level below which worm-burden ceased to have a significant effect on live-weight gain.

Experiment 2. September–November 1951

Nine pairs of non-identical twin lambs, Half-bred × Suffolk, were grazed as a small flock on five paddocks of a total area amounting to about 2 acres. The lambs were moved simultaneously so that they were under the same grazing management on identical pasture.

Bagging and harnessing was similar to that of Experiment 1. To improve the accuracy of the initial and final egg-counts the total daily faecal output was collected during the first and last week of the experimental period. This was not possible over the whole period on account of the number of animals involved. For the remainder of the time only eggs-per-gram counts were made, and these were done in duplicate at weekly intervals using the method of Experiment 1. The first and last counts, however, were done on two successive days to eliminate as far as

possible any error arising from day-to-day fluctuations. The lambs were weighed at weekly intervals and the initial and final live-weights were based on five successive days' weighings. The experiment lasted 50 days. Lambs, as against older sheep, were used in this experiment on account of their greater sensitivity to worm infestation. The egg-counts increased so rapidly, however, that four lambs (Nos. 1*, 3, 9, and 12) were dosed with phenothiazine on the twenty-third day to maintain some animals with low egg-counts.

Results of Experiment 2.—Egg-count and live-weight gain data are presented in Table 5. Egg-counts are expressed as mean eggs-per-gram over the whole period and were derived from the weekly duplicate counts.

TABLE 5. *Data from Expt. 2 with Twin Lambs* (*Twins are bracketed*)

Lamb no.	*L/wt. increase lb.*	*Mean e.p.g. count*
1*	3½	372
1	10¾	2,639
3*	2	943
3	3	769
4*	5¼	640
4	6	466
6*	14¼	1,207
6	7	1,600
7*	3¾	734
7	3½	1,660
8*	13¼	837
8	13	1,049
9*	¾	1,317
9	4½	535
11*	9	823
11	9½	646
12*	2½	616
12	3	387

These results indicate that no correlation could be traced when the group was treated as a whole. However, an interesting fact emerged from a consideration of the animals as pairs of twins. In eight out of the nine pairs the lamb with the higher live-weight gain had also the lower egg-count. The pair which did not conform to this correlation was No. 1. It will be noted that No. 1* was dosed with phenothiazine. This was responsible for a very low egg-count, which was lower than that of its twin before the dosing, thus exaggerating a difference already existing.

Discussion of Results

The results of Experiment 1 indicated that above a certain level of infestation a correlation was observed between live-weight gain and egg-count. However, the limiting level was not clear and the correlation held only within groups. Some indications as to the level below which the worm-burden ceased to have a significant effect on live-weight gain were shown in the contrast between Periods 1 and 2. Within Group *B* the effect of the count of 51 eggs per gram (sheep No. 4) and that of 115 eggs per gram (sheep No. 10) on their live-weight gains appeared distinguishable. These, however, were mean eggs-per-gram counts over 51 days; the differences were at times considerably greater. Gordon and Turner [8], working with infestations well below 300 eggs per gram, state that 'the worm-burdens were relatively very light throughout, and it is not considered that the infestation present would exert other than very slight effects on the growth and productivity of sheep'. The indications from the present work are that even below the 300 eggs-per-gram level infestations may exert a considerable effect on live-weight gain. These effects are, however, not always detectable.

The environmental differences between the groups included the infection to which they were exposed, and it is possible that egg-counts may not have accurately reflected the difference in the level of infestation between groups. Sarles [9], studying the dog hookworm (*Ancylostoma caninum*), concluded that 'egg-production per worm was less in large infestations than in small', and Gordon [10] is in agreement with this. Thus the relatively small difference between eggs-per-gram (and eggs-per-day) counts of the two groups may represent a larger difference in worm-burden.

In Experiment 2, the environmental differences were reduced to a minimum. Nevertheless, the animals differed widely in the infestations that became established, and it seemed that this must primarily be due to differences in natural resistance. In this connexion Fraser and Robertson [11] noted that 'lambs not previously exposed to infestation seem to have a variable natural resistance to stomach worms'. The wide differences in infestation between the twins, whose environment had been similar from birth, support the view that natural resistance may be genetically controlled, as suggested by Clunies Ross and Gordon [12], and consequently amenable to selection. Chandler [13] concluded that 'resistance to acquisition and continued accumulation of worms is influenced by species of host, age, diet, vitamin deficiency, and existing or pre-existing infection with the same species of worm'. In the twins used, most of these factors would be similar.

Since the worm-burdens were larger in Experiment 2 than in Experiment 1, the correlation between egg-count and live-weight gain might have been expected to have been more pronounced. That this was not so might possibly be due to stronger influences controlling live-weight gain. Phillips and Dawson [14] noted that 'type of birth, time of birth, and birth-weight were all related to weights of lambs at three months', and, further, that 'these effects were less marked at 6 months and tended

to disappear at the age of 12 months'. Similarly, Terrill, Sidwell, and Hazel [15] state that 'type of birth had an important effect on body weight'. The effect of birth factors would seem to influence the development and live-weight gain of sheep chiefly in the early part of their lives, and the authors [15] indicate that 'the effect of type of birth on yearling weight is in the same direction but smaller than for weanlings'. Phillips and Dawson [14] conclude, 'in general, there was a tendency for differences in weight due to type of birth to disappear as the animals matured'.

Older sheep may therefore be expected to exhibit a correlation between live-weight gain and worm-burden unobscured by the effect of birth factors that remain operative during early life. This view is supported by previous work on lambs and by the results of Experiment 2. Page [16], after treating lambs with phenothiazine, found that 'results as judged by weight gain did not match those as judged by worm-egg counts'. Leiper [17], dosing the ewes, concluded, 'It is very difficult to correlate weight increases of lambs with egg-count.' In Experiment 2, each pair of twins, although not necessarily identical, had been managed from birth under similar environmental conditions, and the correlations were, in a majority of cases, distinct. Except as between twins, however, it is not possible to show that an animal with a higher egg-count necessarily has a lower rate of live-weight gain than one with a lower count. This would necessitate not only a strict standardization of environment but also an egg-counting technique and sampling methods which were highly sensitive to small differences.

Summary.—The effect of a sub-clinical worm-burden on the live-weight gain of sheep has been studied in two experiments.

Indications were that, even at low levels of infestation, a negative correlation existed between size of worm-burden and live-weight gain.

This correlation may be obscured by environmental influences, including birth factors.

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THE ANALYSIS OF LATTICE DESIGNS WHEN A VARIETY IS MISSING

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THE experimental designs now known as lattices were introduced by Yates in 1936, and have been extensively used since that time for variety trials. They provide a means of testing a large number of varieties or treatments in conveniently small blocks in such a way that all possible comparisons have much the same accuracy. Owing to the large number of different treatments these designs are rather prone to accidents; in particular, it may happen that one variety fails completely and has to be omitted. The present note gives methods of analysing the more common designs when all the plot-yields of a particular variety are missing.

One simple course is open to the experimenter; the results of a lattice experiment can always be analysed as if the experiment were one in randomized blocks, the lattice restrictions being ignored. If this is done the absence of one or more varieties introduces no complication. This procedure is undoubtedly the simplest, and is recommended when the incomplete blocks of the lattice have not proved very efficient in reducing the experimental error.

The randomized-block analysis has two drawbacks. First, a single estimate of error is used for all comparisons between varietal means, although these differ in accuracy owing to the lattice restrictions. Secondly, a certain amount of the available information is ignored, so that varietal comparisons are not made with the full precision afforded by the data. These two disadvantages become important on heterogeneous land when the differences between the incomplete blocks of the lattice are considerable. In this case, the inter-block information will be small, and an analysis based on within-block comparisons only will be satisfactory. The details of such an analysis are given here for simple, triple, and balanced lattices. As a convenient terminology varieties occurring together in a block will be called *neighbours*.

Simple Lattice

Consider a simple $k \times k$ lattice with $r = 2p$ replicates and one variety missing. The steps in the analysis follow those given by Cochran and Cox [Sect. 10. 29 of their book on Experimental Designs, Wiley, New York]:

1. Calculate the block totals, replicate totals, grand total, and variety totals.

2. Set out the block totals in two tables corresponding to the two types of replicate so that blocks containing the same set of varieties occur on the same row. For each row calculate

C = (total over all replicates of varieties appearing in these blocks) − 2 (sum of block totals in the row).

[Empire Journ. of Exper. Agric., Vol. 20, No. 79, 1952.]

As in the ordinary analysis, each varietal total is corrected by adding C/k for each type of block in which it occurs. An additional term is needed for the neighbours of the missing variety; this is given by

$$(k-1)^2P = (C_{X1}-C_{Y1})-(\text{sum of } C\text{'s of the } X \text{ replicates})/k.$$

C_{X1} and C_{Y1} correspond to the blocks containing the missing variety in the X and Y replicates. The quantity P has to be added to the totals of the varieties that neighbour the missing variety in the X replicates, and subtracted from the total of the varieties that neighbour the missing variety in the Y replicates.

3. In the analysis of variance, the sums of squares for replications and treatments unadjusted for blocks are found in the usual way. The sum of squares for blocks adjusted for treatments has two components. Component (*a*) is found by comparing blocks containing the same varieties, and is the total interaction sum of squares from the tables of block totals prepared in step 2 above. This component has $n(p-1)(k-1)$ d.f. and arises only if there are four or more replicates; in its computation, it must be remembered that some of the block totals contain only $(k-1)$ plots. Component (*b*) with $2(k-1)$ d.f. is found from the correction terms as

$$\sum C^2/rk+[(k-1)^2P]^2/r(k-1)^2-(2k^2-1)(\sum C_X)^2/rk^2(k^2-1),$$

where $\sum C_X$ is the sum of the C's of the X replicates.

4. There are six possible error variances for a comparison between two variety means, but average values will usually be sufficient. The necessary formulae are:

	Varieties are	
Pair of varieties contains:	*Neighbours*	*Non-neighbours*
2 neighbours of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+2}{k}+\frac{2}{(k-1)^2}\right)$
1 neighbour of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}+\frac{1}{2(k-1)^2}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+2}{k}+\frac{1}{2(k-1)^2}\right)$
No neighbour of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+2}{k}\right)$
Average values	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}+\frac{1}{(k-1)(k^2-2)}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+2}{k}+\frac{2k}{(k-1)^2(k^2-2)}\right)$

$$\frac{2\sigma^2}{r}\left(\frac{k+3}{k+1}+\frac{2}{(k-1)(k^2-2)}\right).$$

5. If an F test of the varieties is needed, the sum of squares for varieties adjusted for blocks is easily found as

(S.S. for blocks adjusted + S.S. for varieties unadjusted) − (S.S. for blocks unadjusted),

this last term being calculated in the ordinary way from the block totals. The mean square for varieties (adjusted) can then be tested against the error M.S.

As a numerical example, we use the variety trial on soya beans quoted by Cochran and Cox, assuming that the values for variety 1 are missing. Table 1 gives the total yields over four replicates of the varieties, individual plot yields being expressed as (bushels/acre minus 30), together

TABLE 1. 5×5 *Lattice Experiment on Soya Beans*

	Variety totals					*Row sums*	*Block totals*		*Diffs.*	*C*	*C*/5
	1	**2**	**3**	**4**	**5**						
	..	69	37	57	49	212	26	59	−33	+42	+8·4
											+0·5 = +8·
	6	**7**	**8**	**9**	**10**						
	51	51	49	48	56	255	61	81	−20	−29	−5·8
	11	**12**	**13**	**14**	**15**						
	80	42	44	69	72	307	54	65	−11	+69	+13·8
	16	**17**	**18**	**19**	**20**						
	63	50	57	32	62	264	74	75	−1	−34	−6·8
	21	**22**	**23**	**24**	**25**						
	58	64	52	73	55	302	68	68	0	+30	+6·0
Column sums	252	276	239	279	294	1340	283	348	−65	+78	
Block totals	56	80	56	89	87	368					
	61	57	64	75	84	341					
Diffs.	−5	+23	−8	+14	+3	+27					
C	+18	+2	−1	−49	−48	−78					
C/5	+3·6	+0·4	−0·2	−9·8	−9·6						
	−0·5 = +3·1										

with the block and replicate totals and the corrections C. The differences between corresponding pairs of blocks are also given for the calculation of the a component of the S.S. for blocks. P is given by

$$16P = 42 - 18 - 78/5 = +8{\cdot}4, \quad P = +0{\cdot}5.$$

This has to be added to the totals of the X-neighbours of variety 1 and subtracted from those of the Y-neighbours.

The S.S. for blocks, component a, is

$$\frac{20^2+11^2+1^2+0^2}{10} + \frac{33^2}{8} - \frac{65^2}{48} + \frac{23^2+8^2+14^2+3^2}{10} + \frac{5^2}{8} - \frac{27^2}{48} = 168{\cdot}04.$$

The sum of squares for component b is

$$\frac{42^2+29^2+69^2+\ldots+49^2+48^2}{20} + \frac{8{\cdot}4^2}{64} - \frac{49 \times 65^2}{2400} = 637{\cdot}64,$$

so that the complete analysis of variance is as follows:

	d.f.		S.S.	M.S.
Replicates . .	3		166·58	
Blocks—*a* . .	8	168·04		
b . .	8	637·64		
	16		805·68	50·355
Varieties (unadjusted)	23		788·83	
Residual . . .	53		634·74	11·976
Total . . .	95		2395·83	

The error variances are found to be

	Neighbours	*Non-neighbours*
2 neighbours of 1 .	7·186	9·132
1 neighbour of 1 .	7·373	8·570
No neighbours of 1 .	7·186	8·383
Averages . . .	7·251	8·546
	8·114	

The table of adjusted variety totals need not be given in full; we have by way of examples

variety 4 $\quad 57+8\cdot9-9\cdot8 = 56\cdot1$

variety 6 $\quad 51-5\cdot8+3\cdot1 = 48\cdot3$

variety 12 $\quad 42+13\cdot8+0\cdot4 = 56\cdot2.$

The difference in means between varieties 4 and 6 is 1·95, with a standard error of $\sqrt{(9\cdot132)} = \pm 3\cdot02$.

The randomized blocks analysis gives the following analysis of variance:

	d.f.	S.S.	M.S.
Blocks . . .	3	166·58	
Varieties . .	23	788·83	
Error . . .	69	1440·42	20·876
Total . .	95	2395·83	

The variance of the difference of two means is 10·44, so that, relative to the intra-block analysis, the randomized-block analysis has an efficiency of 78 per cent.; in effect, it uses the equivalent of only three out of the four replicates.

Triple Lattice

The analysis is very similar to that of the simple lattice, and will not be described in detail. For each type of block we calculate

$C =$ (total over all replicates of varieties appearing in these blocks) -3 (sum of block totals of this type),

and to each variety total we add three quantities of the form $C/2k$ corresponding to the three types of block in which the variety occurs. Varieties neighbouring the missing variety in replicates X, Y, or Z receive an extra correction P, Q, or R respectively, where

$$2(k-1)(2k-1)P = (2C_{X1}-C_{Y1}-C_{Z1})-(\text{sum of } C\text{'s for } X \text{ replicates})/k$$

$$2(k-1)(2k-1)Q = (2C_{Y1}-C_{Z1}-C_{X1})-(\text{sum of } C\text{'s for } Y \text{ replicates})/k$$

$$2(k-1)(2k-1)R = (2C_{Z1}-C_{X1}-C_{Y1})-(\text{sum of } C\text{'s for } Z \text{ replicates})/k$$

and C_{X1}, C_{Y1}, C_{Z1} refer to the blocks containing the missing variety.

Notice that $P+Q+R=0$. Component (b) of the sum of squares for blocks adjusted for varieties is found as

$$\sum C^2/2rk+\sum[2(k-1)(2k-1)P,Q,R]^2/6r(k-1)(2k-1)$$
$$-(3k^2-1)[(\sum C_X)^2+(\sum C_Y)^2+(\sum C_Z)^2]/6rk^2(k^2-1),$$

where $\sum C_X$, for example, is the sum of the C's for the X replicates.

The error variances for comparisons between two variety means are as follows:

Pair of varieties contains:	*Varieties are* *Neighbours*	*Non-neighbours*
2 neighbours of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}\right)$ if the 2 varieties and the missing variety all occur in the same block; or $\frac{2\sigma^2}{r}\left(\frac{k+1}{k}+\frac{3}{2(k-1)(2k-1)}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+1\frac{1}{2}}{k}+\frac{3}{2(k-1)(2k-1)}\right)$
1 neighbour of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}+\frac{1}{2(k-1)(2k-1)}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+1\frac{1}{2}}{k}+\frac{1}{2(k-1)(2k-1)}\right)$
No neighbour of missing variety	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+1\frac{1}{2}}{k}\right)$
Average values	$\frac{2\sigma^2}{r}\left(\frac{k+1}{k}+\frac{1}{(k-1)(k^2-2)}\right)$	$\frac{2\sigma^2}{r}\left(\frac{k+1\frac{1}{2}}{k}+\frac{3k}{(k-1)(2k-1)(k^2-2)}\right)$

$$\frac{2\sigma^2}{r}\left(\frac{k+2\frac{1}{2}}{k+1}+\frac{3}{(2k-1)(k^2-2)}\right).$$

Balanced Lattice ($(k+1)$ *replicates*)

This is a special case of balanced incomplete blocks, and a slightly different analysis is available. For each variety calculate

Q = (variety total over all *replicates*)
−(sum of means of all blocks containing the variety).

In practice it is simpler to calculate $k(k-1)Q$, using block totals. The (k^2-1) varieties can be divided into $(k+1)$ sets according to the replication in which they neighbour the missing variety. Calculate the sum of the Q's for each set. Then each adjusted variety mean is given by

$$k(k-1)(k^2-1)v = k(k-1)(k^2-1)\times\text{general mean}+(k-1)(k^2-1)Q$$
$$+(\text{sum of } Q\text{'s for set containing the variety}).$$

The sum of squares for varieties adjusted for blocks can be obtained directly as $\sum(Qv)$.

For the standard errors, note that any two varieties are neighbours in one block of the design. If this block contains the missing variety, the error variance of the difference between the two means is $\frac{2\sigma^2}{k+1}\left(\frac{k+1}{k}\right)$; if

not the error variance is $\frac{2\sigma^2}{k+1}\left(\frac{k+1}{k}+\frac{1}{k(k-1)^2}\right)$. The average value is $\frac{2\sigma^2}{k+1}\left(\frac{k+1}{k}+\frac{1}{(k-1)(k^2-2)}\right)$.

For an example of this analysis, we use the 3×3 balanced lattice given by Cochran and Cox [Section 10. 1]. The figures represent gains in weight (lb. per day) of pairs of pigs on different diets. We suppose for the sake of example that diet 1 proved insufficient and had to be abandoned. The rest of the data is given in Table 2.

TABLE 2. *3 × 3 Balanced Lattice Experiment on Pigs*

Rep. 1				*Rep. 2*			
1	**2**	**3**	*Totals*	**1**	**4**	**7**	*Totals*
..	1·84	2·18	4·02	..	1·20	1·15	2·35
4	**5**	**6**		**2**	**5**	**8**	
2·05	0·85	1·86	4·76	2·26	1·07	1·45	4·78
7	**8**	**9**		**3**	**6**	**9**	
0·73	1·60	1·76	4·09	2·12	2·03	1·63	5·78
			12·87				12·91
Rep. 3				*Rep. 4*			
1	**5**	**9**		**1**	**6**	**8**	
..	1·16	1·11	2·27	..	1·57	1·43	3·00
2	**6**	**7**		**2**	**4**	**9**	
1·76	2·16	1·80	5·72	1·50	1·60	1·42	4·52
3	**4**	**8**		**3**	**5**	**7**	
1·71	1·57	1·13	4·41	2·04	0·93	1·78	4·75
			12·40				12·27

The necessary computations are as follows:

	Treatment totals	*6 × Block corrections*	$6Q$	$6(16Q+\Sigma Q)$	$v = G/32 + 6(16Q+\Sigma Q)/288$
2.	7·36	42·10	+2·06	+41·38	1·72
3.	8·05	41·94	+6·36	+110·18	1·96
4.	6·42	34·43	+4·09	+66·12	1·81
5.	4·01	35·39	−11·33	−192·68	0·91
6.	7·62	41·52	+4·20	+69·50	1·82
7.	5·46	36·17	−3·41	−53·88	1·39
8.	5·61	35·56	−1·90	−28·10	1·48
9.	5·92	35·59	−0·07	−12·52	1·53
	$50·45 = G$	$302·70 = 6G$	0·00	0·00	

sums of $6Q$'s

2, 3	+8·42
4, 7	+0·68
5, 9	−11·40
6, 8	+2·30
	0·00

The analysis of variance is

	d.f.	S.S.	M.S.
Replicates . . .	3	0·0386	
Blocks (unadjusted) . .	8	1·9809	
Treatments (adjusted) .	7	2·1811	0·3116
Residual . . .	13	1·1415	0·0878
Total	31	5·3431	

The error variances are

$$\frac{2\times 0\cdot 0878}{4}\times\frac{4}{3}=0\cdot 0585 \quad \text{and} \quad \frac{2\times 0\cdot 0878}{4}\left(4+\frac{1}{3\times 4}\right)=0\cdot 0622$$

with an average value of

$$\frac{2\times 0\cdot 0878}{4}\left(\frac{4}{3}+\frac{1}{2\times 7}\right)=0\cdot 0617.$$

Summary.—The analysis is presented of simple, triple, and balanced lattice designs where one variety or treatment is missing in all replications. The analysis uses intra-block information only. When the incomplete blocks are not very variable it is recommended that a randomized block analysis be used.

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STUDIES ON THE FERTILITY OF GOLD COAST SOILS

Pt. IV. THE POTASSIUM AND CALCIUM STATUS OF THE SOILS AND THE EFFECTS OF MULCH AND KRAAL MANURE

P. H. NYE[1]

THE fertilizer trials in which muriate of postash, lime, mulch, and kraal manure were treatments were described in Part I of the series (this J., 1951, **19**, 217). In 1948 there were 45 trials of a 2^5 factorial design, and they all included the following treatments: muriate of potash, 0 and 2 cwt. per acre; lime, 0 and 10 cwt. per acre (5 cwt. per acre in the far north); mulch, 0 and 5 tons dry wt. of grass or straw per acre.

In 1949, 16 fresh trials with the same treatments were begun; and 24 of the 1948 trials were continued, the treatments being repeated, except that no more lime was spread, and on one of the two sites at each place in the Northern Territories 4 t. per acre of kraal manure was substituted for mulch.

There were no trials with different levels of application for any of these treatments, with the exception of ten trials in 1949 of a 3^3 factorial design on groundnuts in which lime at 0, 5, and 10 cwt. per acre was one of the treatments.

Effects of Potash

The effects of the application of 2 cwt. per acre of muriate of potash in all the trials, and averaged over all other treatments, are shown in Table 1.

There is no evidence that the application of potash had beneficial effects on any of the crops or soils. The three significant positive effects may reasonably be ascribed to chance, as there was a large number of trials.

The depression of the yield of early millet is the result of a depression of germination and early growth (cf. Pt. I). This reason can sometimes be offered for the depression of the yield of groundnuts, but there are several instances in which the yield of nuts is significantly depressed, although the germination and appearance of the plants is as good on the plots treated with potash as on those not treated. On yams the very marked depression of yield does not show in the germination or the leaves of the growing crop.

Effects of Lime

The effects of the application of 10 cwt. per acre of lime (5 cwt. per acre in the far north) are shown in Table 2.

It has been mentioned that the pH values of the top soils of all trial sites lie between 5·5 and 7·5, and so they would not be expected to show great benefits from liming. The only crop on which lime has had any

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TABLE 1. *Potash Effects*

Crop	No. of trials with: Positive effects: sig. at $P = 0.05$	Positive effects: not sig.	Negative effects: sig. at $P = 0.05$	Negative effects: not sig.	Total no. of trials	Mean response %
1. *Forest and Southern Fringing Forest: (a) Undisturbed sites**						
Maize (1)†. . .	0	5	0	4	9	−2
Maize (2) . . .	0	3	0	0	3	8
Cassava . . .	0	2	0	1	3	2
(*b*) *Disturbed sites*						
Maize (1) . . .	0	2	2	3	7	−3
Cassava . . .	0	1	0	3	4	−4
Groundnuts (1) and (2)	0	1	1	1	3	−7
2. *Savannah. Voltaian soils: (a) Long-resting-period sites*						
Maize . . .	0	3	0	1	4	5
Cassava . . .	0	0	1	0	1	−18
Guinea-corn . .	0	1	1	2	4	−3
Sunflower . . .	0	2	0	0	2	10
Yams . . .	0	0	1	2	3	−9
Groundnuts . .	0	2	3	3	8	−5
(*b*) *Short-resting-period sites*						
Maize . . .	0	1	0	6	7	−8
Guinea-corn . .	1	3	0	0	4	11
Yams . . .	0	1	1	1	3	−12
Groundnuts . .	1	1	0	2	4	0
3. *Savannah. Northern granite soils*						
Guinea-corn . .	0	2	0	3	5	−3
Late millet . .	1	1	0	1	3	2
Early millet . .	0	2	2	2	6	−5
Groundnuts . .	0	0	1	2	3	−6
4. *Savannah. Greenstone soils*						
Guinea-corn . .	0	2	0	0	2	8
Late millet . .	0	1	0	0	1	2
All sites						
Maize . . .	0	14	2	14	30	−1
Guinea-corn . .	1	8	1	5	15	3
Late millet . .	1	2	0	1	4	2
Early millet . .	0	2	2	2	6	−5
Cassava . . .	0	3	1	4	8	−4
Yams . . .	0	1	2	3	6	−10
Groundnuts . .	1	4	5	8	18	−5

* See Part I for an explanation of the grouping of the sites.
† (1) first season. (2) second season.

appreciable effect is groundnuts. The effect is never great, and it is fairly consistent over all the sites on which groundnuts were grown. In a few of the trials the lime-treated plots showed a better growth of leaves.

TABLE 2. *Effects of Lime*

Crop	No. of trials with: Positive effects: sig. at $P = 0.05$	Positive effects: not sig.	Negative effects: sig. at $P = 0.05$	Negative effects: not sig.	Total no. of trials	Mean response %
1. *Forest and Southern Fringing Forest: (a) Undisturbed sites*						
Maize (1)	0	8	0	1	9	4
Maize (2)	0	2	0	1	3	5
Cassava	0	2	0	1	3	10
(*b*) *Disturbed sites*						
Maize (1)	0	4	0	3	7	1
Cassava	0	1	0	3	4	−1
Groundnuts	1	2	0	0	3	5
2. *Savannah. Voltaian soils: (a) Long-resting-period sites*						
Maize (1) and (2)	0	1	0	3	4	−2
Guinea-corn	0	2	0	2	4	1
Yams	0	1	0	2	3	−1
Cassava	5	1	0	0	1	4
Sunflower	0	2	0	0	2	−8
Groundnuts	2	8	0	3	13	4
(*b*) *Short-resting-period sites*						
Maize	0	3	0	4	7	0
Guinea-corn	0	2	0	2	4	3
Yams	1	2	0	0	3	5
Groundnuts	4	1	0	2	7	10
3. *Savannah. Northern granite soils*						
Guinea-corn	0	3	0	2	5	−2
Late millet	0	3	0	0	3	4
Early millet	0	5	0	1	6	4
Groundnuts	0	6	0	0	6	4
4. *Savannah. Greenstone soils*						
Guinea-corn	0	2	0	0	2	7
Late millet	0	0	0	1	1	−8
All sites						
Maize	0	18	0	12	30	2
Guinea-corn	0	9	0	6	15	2
Late millet	0	3	0	1	4	0
Early millet	0	5	0	1	6	4
Sunflower	0	2	0	0	2	−8
Yams	1	3	0	2	6	1
Cassava	0	4	0	4	8	4
Groundnuts	7	17	0	5	29	5

In the ten trials with both 5 and 10 cwt. per acre dressings of lime on groundnuts, there was no appreciable difference between the effects at the two rates.

As mentioned in Pt. III (No. 77, p. 50), the shelling percentage for the twelve groundnut trials in 1948 was about 70, a reasonably high figure. None of the treatments showed any marked effects or significant trends; and the effect of lime cannot be accounted for in this way.

Potash and lime interaction.—The value of the potash and lime interaction for the main trial crops is as follows:

Crop	No. of trials with: Positive effects, sig. at $P = 0{\cdot}05$	No. of trials with: Positive effects, not sig.	No. of trials with: Negative effects, sig. at $P = 0{\cdot}05$	No. of trials with: Negative effects, not sig.	Total no. of trials	Potash × lime interaction %	Lime response %	Potash response %
Maize	0	18	0	12	30	1	2	−1
Guinea-corn	0	11	0	4	15	1	2	3
Yams	1	5	0	0	6	7	1	−10
Groundnuts	1	12	0	5	18	2	5	−5

The value of the interaction on yams is high and consistent, and on groundnuts it is small but fairly consistent. It implies that in the presence of lime, the bad effect of potash on yams is greatly reduced, and this is so to a lesser extent on groundnuts.

Effects of Mulching

The mulch, applied at the rate of 5 t. dry weight per acre of grass or straw, was sufficient to give a cover of about ½ in. over the surface when the crops were planted on the flat. If the crop was planted on the ridge the top of the ridge was bare and the mulch covered the furrow and halfway up the sides. In Table 3 the results of the mulch treatment, averaged over all other treatments, are summarized. Owing to the possibility that the mulch might influence the nitrogen and phosphate status of the soil, the interactions of mulch with nitrogen and with phosphate are also included.

In the forest the effect of the mulch is beneficial on maize, cassava, and groundnuts, though the results are modest. There was evidence in the two maize and two cassava trials at Kwadaso that the decomposing mulch released phosphate to the plants and this was partially responsible for its effect. Where mulch had a negative effect the sites were rather wet.

On the Voltaian soils that had been recently cleared after a long rest under bush, the effect of the mulch on the cereals was much reduced. In one instance, on guinea-corn at Yendi site 1, this was due to a depressing effect on the supply of available nitrogen, but the low average value of the nitrogen × mulch interaction shows that this effect does not in general provide the reason. The very high effect in one sunflower trial was due to a lowering of the incidence of a Schlerotinium wilt on the mulched plots. The effect on groundnuts was high and remarkably consistent. The effect on yams was small. On the more frequently cropped Voltaian soils the effect on cereals and yams was rather greater, but on groundnuts less.

In the far north the increase in the yield of cereals was small, though the percentage increase was higher than on maize in the forest. Groundnuts showed a negative response, for which a possible explanation is that

TABLE 3. *Effects of a Straw Mulch*

Crop	No. of trials with: Positive effects: sig. at $P = 0{\cdot}05$	Positive effects: not sig.	Negative effects: sig. at $P = 0{\cdot}05$	Negative effects: not sig.	Total no. of trials	Mean response %	Mean nitrogen × mulch interaction %	Mean phosphate × mulch interaction %
1. *Forest and Southern Fringing Forest: (a) Undisturbed sites*								
Maize (1)	3	3	1	2	9	9	−4	−2
Maize (2)	2	1	0	0	3	27	−5	2
Cassava	0	1	0	2	3	5	6	0
(b) Disturbed sites								
Maize (1)	3	2	0	2	7	7	0	−1
Cassava	0	4	0	0	4	4	−2	0
Groundnuts	1	1	0	0	2	16	1	8
2. *Savannah. Voltaian soils: (a) Long-resting-period sites*								
Maize	0	2	0	1	3	1	−4	0
Guinea-corn	0	0	1	3	4	−12	5	−6
Sunflower	1	0	0	1	2	20	5	−1
Cassava	1	0	0	0	1	9	−1	−2
Yams	0	2	0	1	3	1	2	0
Groundnuts	8	0	0	0	8	19	1	−1
(b) Short-resting-period sites								
Maize	2	4	0	1	7	7	3	4
Guinea-corn	1	1	0	1	3	9	−6	2
Yams	0	3	0	0	3	5	−3	1
Groundnuts	2	1	0	0	3	7	−1	−1
3. *Savannah. Northern granite soils*								
Guinea-corn	2	0	0	1	3	19	−5	5
Late millet	0	1	0	0	1	(10)	(6)	(12)
Early millet	0	2	0	0	2	15	9	−2
Groundnuts	0	1	0	2	3	−2	−1	−1
4. *Savannah. Greenstone soils*								
Guinea-corn	1	0	0	0	1	(31)	(8)	(3)
All sites								
Maize	10	12	1	6	29	8	−2	−1
Guinea-corn	4	1	1	5	11	6	0	0
Late millet	0	1	0	0	1	(10)	(6)	(12)
Early millet	0	2	0	0	2	15	9	−2
Sunflower	1	0	0	1	2	20	5	−1
Cassava	1	5	0	2	8	5	0	0
Yams	0	5	0	1	6	2	0	1
Groundnuts	11	3	0	2	16	13	0	0

the plants need less not more moisture during the heavy August and September rains while the nuts are maturing.

In general the absence of well-marked interactions with nitrogen and phosphate show that the effect of the mulch is mainly physical. It is impossible to decide whether the beneficial effects are due to a lowering of soil temperature or to the conservation of moisture. Other effects

noted are a depression of weed-growth on the mulched plots, and a looser top soil beneath the mulch on soils that tend to pan.

Effects of Kraal Manure

In some trials in the Northern Territories 4 t. per acre of kraal manure was substituted for mulch in 1949. Comparisons between dung and the inorganic fertilizers are not rigorous, because the dunged plots in 1949 had received mulch the previous year; and also the fertilizer effects, with which the effect of dung are compared, include any use the crops may have made of the previous year's application of fertilizers.

In Table 4 the effects of dung in each of the trials where it was used are compared with the effects of phosphate and nitrogen. The first-order interactions are also shown.

TABLE 4. *Effects of Dung, Nitrogen, and Phosphate, and their Interactions*

Site	*Crop*	*Main effects (%)*			*Interactions (%)*		
		Nitrogen	*Phosphate*	*Dung*	*N×P*	*N×D*	*P×D*
Yendi 2	Maize	33†	21*	3	−29†	6	2
Nyankpala 8	Groundnuts	−10*	−8	−10*	4	−2	2
Tamale 1	Guinea-corn	49†	23	9	1	14	−1
Manga 2	Early millet & guinea-corn	30†	49†	20*	26†	4	−23†
		41†	16	46†	20	−6	−15
Tono 2	Early millet & late millet	36†	84†	64†	29*	20	−24*
		11	14*	28*	4	4	−14*
Zuarungu 2	Early millet & late millet	6	13	−13	−1	−11	−8
		56†	40†	45†	34*	−13	13
Zuarungu 1	Early millet & guinea-corn	10	68†	32†	26*	16	−13
		failed					
Zanlerigu 2	Late millet	38*	10	47*	−5	28	−24

* sig. at P = 0·05. † sig. at P = 0·01.

When the phosphate effect is high there is a high negative phosphate × dung interaction, which suggests that the main effect of the dung is to supply phosphate. For the quick-maturing crops, maize and early millet, phosphate is in every instance superior. For the slower-maturing crops, dung is better in four cases out of five. The late millet trial at Zanlerigu, which was particularly favourable to dung, is on reddish-brown friable clay with a high phosphate-fixing capacity.

A discussion of the economic possibilities of using fertilizers is being deferred until the results of a widespread series of trials on native farms in 1950 have been assembled.

Summary

No good effects from a dressing of muriate of potash have been observed on any crops, and on early millet, groundnuts, and yams the yields are decreased.

Groundnuts are the only crop that responds to lime. The increases will not pay for the cost of the lime. When lime is applied the bad effect of potash on groundnuts and yams is much reduced.

Mulching has given moderate increases in the yields of all crops, particularly groundnuts.

Dung was substituted for mulch in some of the trials in the Northern Territories. It owes its effect primarily to its phosphate-content. It was less effective than superphosphate on early-maturing crops, but more effective on the late-maturing ones.

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A COTTON STAINER (*DYSDERCUS SUPERSTITIOSUS* FABR.) AS A POTENTIAL PEST OF SORGHUM

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THE members of the genus Dysdercus (Heteroptera, Pyrrocoridae) feed on the ripening or mature seeds of a wide variety of trees, shrubs, and herbs. The known host-plants (defined as those on which breeding occurs as distinct from food-plants on which feeding, but not breeding, occurs) fall within the order Malvales, which includes the Malvaceae, Tiliaceae, Bombacaceae, and Sterculiaceae. The importance of the genus arises from the large number of species occurring as pests of cultivated cotton in nearly all cotton-growing countries throughout the world. They injure both seeds and lint of cotton by their feeding, and they also transmit the fungi of internal boll disease. It is the staining associated with internal boll disease that has given them the name of cotton stainers. In the African cotton-growing areas, seven species are considered as major pests, and one of these, *D. superstitiosus*, is the dominant species in Nigeria.

During investigations into the behaviour of Dysdercus spp. in southern Nigeria, Pomeroy and Golding identified the host- and food-plants of *D. superstitiosus* in that area, and determined the annual cycle of breeding, feeding, and migration. In the two published accounts of this work [1, 2] mention is made of the occurrence of adults in the field on bulrush millet, and on sorghum. Attempts to breed the species on sorghum were unsuccessful [1], but the appearance of the adults on sorghum in large numbers, during November, appeared to be a regular occurrence [2].

No detailed observations on the behaviour of *D. superstitiosus* have been reported from the northern Provinces of Nigeria where the bulk of exportable cotton is grown. The northern cotton areas, centred on Zaria, have a rainy season lasting from late March to early October, which is followed by a severe dry season. The climate is admirably suited for both cotton and grain crops and the staple food-crops include bulrush millet (*Pennisetum typhoideum*) and sorghum. During each of the three seasons 1948–50, when the writer carried out a survey of insects attacking cotton in this area, adults and nymphs of *D. superstitiosus* were observed feeding on the immature grains of bulrush millet during July and August. There appeared in fact to be a prolonged period of feeding on this crop from the first formation of the grains until harvesting, which is normally 4 weeks later. This is long enough to enable one generation of adults to be bred if egg-laying occurs shortly after the migrant adults enter the crop. The extent to which this occurred was not ascertained, but it was noted that at the time of harvesting the stainer population consisted mainly of adults and fifth instar nymphs. As soon

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as the millet was harvested the adults dispersed, and on one occasion [3] on a plot of cotton sown exceptionally early (June 9) a large immigration of adults occurred at the time of the millet harvest. Normally adults entered the July-sown main cotton crop in late September and early October in response to the flowering of the crop: one generation matured on the cotton and the adults dispersed during November and December. In contrast to observations made by the earlier investigators in the southern Provinces, adults were never recorded on the peasant sorghum crops, and in seeking an explanation of this difference the sequence of flowering of these three crops is important.

Bulrush millet is the first grain crop to flower during July. The cotton, which is sown during July, begins flowering in September and reaches a peak by early October. Sorghum, which is the first crop to be sown when the rains start, does not 'head' until late October. By this time the stainers have distributed themselves amongst cotton and other minor crops such as *Hibiscus cannabinus*, and when they leave the cotton during November and December the sorghum has been harvested. Under the northern conditions, therefore, it appears that the bulrush millet tides the stainer over a period when there are no other hosts in a suitable condition for feeding. On the other hand, sorghum is not utilized, as it flowers and matures later, at a time when there is an adequate supply of other hosts in a suitable condition.

There was no suggestion that the stainers caused any serious damage to either the sorghum or millet crops in the south, and there was no evidence that the millet in the north suffered appreciably from the feeding of adults or nymphs. That *D. superstitiosus* can behave as a serious pest of sorghum under certain conditions was, however, abundantly illustrated by an outbreak which occurred in 1950 at Mokwa, about 100 miles south of the main cotton area. Mokwa is in the middle agricultural zone, a distinct belt of country in the southern half of the northern Provinces.

The conditions in which the attack developed were as follows. A pilot scheme was projected to investigate the possibility of bringing into cultivation a large area of unoccupied land. Clearing, initial cultivation, and harvesting were to be mainly mechanized, whilst tending of the crops was to be the responsibility of settled peasants. One of the objects of the scheme was to use at least one-third of the land each year for the production of sorghum. During 1949 and 1950, 4,800 acres had been cleared, and in 1950 a little over 2,000 acres were sown under various crops for the first time, in large blocks, as below:

	acres		*acres*
Sorghum . . .	900	*Hibiscus cannabinus* (for fibre) .	230
Groundnuts . . .	300	Soya beans	150
Sunflower . . .	500	Cotton (observational) . .	16

In November the writer was asked to investigate a severe attack of stainer on the sorghum. A very brief visit was made at the end of the month, and adults and nymphs of *D. superstitiosus*[1] were observed feeding

[1] Identified by the Commonwealth Institute of Entomology, London.

on the heads over a large area of the crop. Severe damage was apparent, the seeds being grey, dried, and withered, and bearing small black spots with a central callus. The damage was very similar to that caused by the Pentatomid *Agonoscelis versicolor*, a pest of sorghum in the Sudan. The illustration of sorghum damaged by this insect in Whitfield's paper [4] could equally represent damage caused by *D. superstitiosus*. At that time, when the grains were just passing the milky stage, about one-third of the crop could be written off as a complete loss. From this severely damaged area the stainers appeared to be spreading across the remainder of the crop, and there were thus three distinct zones discernible:

(*a*) The severely damaged area in which only isolated stainers were observed.
(*b*) The adjacent area in which they were concentrated, having moved from the zone (*a*) where their activity had rendered the heads useless as food.
(*c*) Beyond (*b*) an area equal to about half the crop which was in good condition, and showing comparatively few stainers, but where nevertheless nymphs were present in addition to adults.

Adults and nymphs were also observed on the crop of *H. cannabinus*, which was still flowering, and bore ripening fruits. This crop, however, was adjacent to zone (*c*) of the sorghum, and this ruled out the possibility that this was the source of the main infestation.

Three main factors were probably concerned in bringing about this attack. First, the area chosen for the scheme was one in which earlier surveys had shown that *D. superstitiosus* was a limiting factor in cotton production. This would have been due largely to the presence of a wide range of wild hosts on which the species survived between successive cotton seasons. It is possible that the sudden clearing of 5,000 acres may have aggravated this situation by temporarily concentrating the indigenous population of stainers around the cleared area. Secondly, a small variety trial of a number of sorghums, sown before the main crop, was held early in the season. This contained mainly early maturing varieties that were harvested during August and September. These varieties would have been in a soft-grained stage during July and August, when the peasant crops were still two months from flowering, and at a time when, as indicated above, this stainer normally feeds on bulrush millet. It was not surprising, therefore, that stainers were in fact observed feeding on these plots. Thirdly, the main sorghum crop was sown with 'Kaura', a semi-dwarf, close-panicled variety (to facilitate mechanical harvesting), in contrast to the peasant crop which consists exclusively of 'Fara Fara', the tall, open-panicled type. On the latter no stainers were observed in the Mokwa area.

Though no continuous observations on the development of this attack were available, the probable sequence of events can be reconstructed with some confidence, as follows: An initial migration to the variety trial was actually noted, and it appears that breeding took place on the plots of early maturing varieties. The juxtaposition of the trial and the later flowering main crop enabled the resulting generation of

adults to initiate an infestation in the main crop. The very large population of all nymphal stages, but mostly 3rd–5th instars, present at the end of November, was, however, the last generation bred on sorghum. It seems likely that the majority of the older nymphs matured to adults and dispersed before the crop ripened, for a second inspection a month later revealed that the stainer population had diminished to isolated adults, and about half the crop was ready for harvesting relatively free from damage. The development of an attack on this scale was, of course, unpredictable and is quite unprecedented. It is possible that without the early varieties in the trial the main crop would have escaped. On the other hand, the attack on the early strains shows that to plant the main crop with one early maturing variety would involve the risk of a serious infestation developing from an immigration of adults during July and August. It was therefore recommended that in future the tall, open-panicled type of sorghum should be grown. This was done, and in the following season there was no recurrence of the attack.

Although the situation observed in the field demonstrated unquestionably that *D. superstitiosus* had bred on the sorghum crop, this evidence contradicted the results of Golding's earlier experiments. Accordingly, after being transferred to Uganda early in 1951, the writer repeated Golding's experiments, and succeeded in breeding this stainer through its complete life-cycle on immature sorghum grains. The sorghum used was obtained from the eastern province of Uganda and consisted of early maturing varieties very similar in appearance to the type grown at Mokwa in 1950. A culture of the stainer is in fact being maintained entirely on grains in the same soft milky stage which Golding used. This immediately suggests that sorghum varieties may differ in their suitability for stainer breeding, and that Golding happened to choose an unsuitable or 'resistant' variety. Some evidence in favour of this theory has recently been reported from northern Nigeria, where A. F. H. Baillie has been studying the biology of *D. superstitiosus*. He planted a host preference trial in such a way as to bring both dwarf and tall sorghums into flower in the first week of October, when *D. superstitiosus* is moving on to fresh host-plants. On the dwarf form the stainers bred profusely and Baillie recorded 550 nymphs per 100 heads. On the tall type grown by the peasants, though flowering coincided with that of the dwarf, only 16 nymphs per 100 heads were recorded. There may in fact have been no breeding on this type, for the few nymphs recorded might have migrated from the adjacent dwarf variety. Further laboratory tests should demonstrate whether such results are due to intrinsic differences in sorghum varieties.

There thus seem to be two factors involved in determining whether in any given locality *D. superstitiosus* may develop as a serious pest of sorghum. The first is the time of flowering of the crop in relation to a migration of adult stainers. The second is the extent to which the sorghum variety is suitable for stainer breeding. In northern Nigeria the late maturation of the indigenous peasant variety, and its apparent unsuitability for breeding, prevent *D. superstitiosus* from behaving as a pest. On the other hand, the situation at Mokwa in 1950 was demonstrably

the reverse of this and resulted in a serious outbreak. There, however, the pilot scheme served the purpose for which it was planned, viz. to find out the best way of growing sorghum on a large scale under local conditions, and incidentally showed that *D. superstitiosus* can be a limiting factor in sorghum production.

There are other African territories where *D. superstitiosus* occurs [5–8], e.g. Northern and Southern Rhodesias, Tanganyika, southern Sudan, and where sorghum is either already a major food crop, or is being grown on an increasing scale. It is therefore most important that in such areas the suitability of both new varieties and new methods of cultivation should be fully appraised before any innovations are made.

Summary

The known host-plants, i.e. those on which breeding occurs, of the genus Dysdercus are all included in the order Malvales. Early workers in southern Nigeria recorded adults of *D. superstitiosus* feeding, but not breeding, on bulrush millet and sorghum. This species was noted breeding on bulrush millet in northern Nigeria during 1948–50; and in 1950 a severe attack, due to extensive breeding, occurred on a large crop of dwarf sorghum. The conditions under which this outbreak occurred are described, and its probable causes indicated.

The evidence obtained in the field suggests that in northern Nigeria the indigenous peasant variety, a tall late-maturing type which is grown exclusively for food, may be 'resistant' to stainer-breeding, but the dwarf variety appears to be particularly susceptible. In Uganda the writer has bred the stainer through its complete life-cycle on dwarf varieties obtained from the eastern provinces of that territory.

The significance of this apparent change in stainer-behaviour is discussed, particularly with reference to new or established sorghum-growing areas in other African territories.

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THE NUTRITIVE VALUE OF WEEDS AND COARSE HERBAGE (BROWSE) FOR YOUNG CATTLE GRAZING A TEMPORARY PASTURE

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SOME agronomists believe that the presence of weeds and coarse herbage (browse) in a pasture is nutritionally advantageous for grazing animals. Stapledon [1] has defined browse as herbage in many stages of maturity and consisting of a wide range of species. *Per contra* others believe that a productive ley consisting of stimulated herbage of only a few selected species, all at comparable stages of maturity, provides at least an equally effective diet for grazing stock. Neither opinion appears to be founded upon experimental results; both arise from different interpretations of the observed behaviour of grazing animals. It has frequently been reported that, if given the opportunity, animals confined upon 'productive grass' will avidly graze weeds of the hedgerow and ditch [2]. If it is accepted that animals possess an 'appetite instinct' that enables them to select a diet ideally suited to their nutritional requirements, it follows that the weeds or browse are an essential item in the diet. If, on the other hand, the 'appetite instinct' theory is rejected, then on grounds of maximum production of digestible nutrients per acre the management of a ley for productive grass alone would be desirable. The literature dealing with the experimental evidence for and against the belief in an 'appetite instinct' has recently been reviewed [3] and has been shown to be confused and contradictory.

The present paper describes an experiment to find out if browse is of any nutritional significance to young grazing stock: one group of young animals was given productive grass alone and a similar group productive grass plus browse.

Experimental area.—Eight acres of land were divided into two equal rectangular plots, *A* and *B*, and were sown on May 16, 1949, for grazing in 1950. Plot *A* was drilled with a seeds-mixture recommended as particularly suitable for local conditions by the Grassland Department of the North of Scotland College of Agriculture (Table 1). This was designed to give a luscious, high-quality sward capable of good production throughout a growing-season.

Plot *B* was divided into a major portion, *Bi* (3½ acres), and a narrow strip, *Bii* (½ acre). The former was drilled with the same mixture as *A*,

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but the latter was broadcast with a different mixture, consisting chiefly of commercial strains of grasses and including a proportion of 'weeds' seeds, designed to give a rougher sward of coarse vegetation (Table 1).

TABLE 1. *List of Strains, Species, and Seed-rates of Herbage Plants sown*

Seeds-mixtures			
Plots A and Bi	*lb./acre*	*Plot Bii*	*lb./acre*
H.I. ryegrass	3	Italian ryegrass	3
Ayrshire perennial ryegrass	6	Irish perennial ryegrass	10
Devon eaver	4	New Zealand perennial ryegrass	4
S. 23 ryegrass	4	American cocksfoot	8
S. 37 cocksfoot	3	American timothy	4
Danish cocksfoot	2	Late-flowering red clover	1½
S. 143 cocksfoot	3	S. 100 white clover	1
S. 48 timothy	4	'Cleanings' mostly plantain and yarrow	4½
S. 123 red clover	1½		
S. 100 white clover	1		
Total	31½	Total	36

The following methods were employed to reduce the availability of 'browse' to a minimum in plot *A*, while maintaining it at a maximum in plot *B*:

Plot A. Besides heavy grazing by adult dairy cows in the summer of 1949 before the experiment started, the plot was hand-weeded during March and April 1950, and at the beginning of April it was sprayed with one-third of a pint of phenoxylene per acre. To ensure that the productive grass should not produce mature 'browse' for the cattle in plot *A* by growing more quickly than it was grazed, an Allen motor-scythe was used to top the sward when necessary. The botanical analyses show that plot *A* was weed-free; during the experiment it was completely surrounded with an electric fence except for one point of access to a stream for drinking.

Plot B. This plot was enclosed by an electric fence on two sides only. The remaining sides, bordering both *Bi* and *Bii*, were formed by the bank of a stream to which the experimental animals had access. No weeding or spraying was carried out on plot *B*. The self-established herbs, plus those sown in *Bii* and the numerous plants on the stream bank, together with the commercial strains of grasses in *Bii*, made available to the grazing animals a wide variety of species in different stages of growth.

The fertility of the whole area was high. Pigs were folded across it before the experimental mixtures were sown, and in addition to the manuring received during the grazing of dairy cattle during 1949 the whole experimental area received 4 cwt. potassium phosphate per acre in November 1949, 2 cwt. Nitro-chalk per acre in both March and July 1949, and 2 cwt. of an NPK compound fertilizer (I.C.I. no. 1) per acre in June 1950.

Electric fences were erected round each plot in March 1950, and grazing with the experimental animals began in the first week of May.

To relate the performance of the animals with the composition of the swards they were grazing, changes in the flora and in the animals were recorded. The first part of this paper therefore describes the botanical development of this study, and it is against this background that the animal observations in the second part should be studied.

Observations on Pasture Establishment and the Development of the Weed Population (C. H. Gimingham)

The objects of the botanical observations were twofold:

(i) A comparison of the proportions in which seedlings of the various species of grass and clovers became established, with their proportions in the seeds-mixtures.

(ii) A record of the change in weed population throughout the experiment and its relation to grazing management and other treatments.

Method.—On all occasions sampling was carried out from ten equidistant points along each of four transects in plots *A* and *Bi*, and along two transects in *Bii*. The sampling points were located approximately by pacing the distances along the transects.

(i) In order to ascertain the proportions in which seedlings of the various species became established, samples were taken by quadrate mesh 6 × 6 in. The mesh was placed so that the direction of one drill ran from the centre of one side to the centre of the opposite side. The number of seedlings of each species inside the square was counted.

(ii) The composition of the sward (grasses and clovers) at various times during the experiment was analysed by the point quadrate method [4].

(iii) Counts of the weed population were made from squares of $\frac{1}{4}$ sq. metre in area.

(iv) The species occurring in the portions of hedge and bank available to the animals in section *B* were recorded.

Results

The proportional establishment of species and their development during the experiment

(*a*) *The proportional establishment of species.* The seeds-mixtures employed are shown in Table 1. Both for *A* and *Bi* and for *Bii* the proportions of the various species were:[1] ryegrass 17; cocksfoot 8; timothy 4; red clover $1\frac{1}{2}$; white clover 1.

At the time of sowing the only grasses recorded on the field were smooth-stalked meadow-grass, perennial ryegrass, and bent (*Agrostis stolonifera*). These came into flower about the time the seedlings appeared.

[1] In the botanical analyses it has been impossible to distinguish strains. Also, since much of the work has been done with young shoots, no attempt was made to distinguish between perennial and Italian ryegrass, nor between white and red clover.

The seedling count was made on July 2, 1949, and the results showed that in plots *A* and *Bi* the three grass species sown were established approximately in the proportions in which they were represented in the seeds-mixture, though timothy was perhaps slightly lower than expected.

In the *Bii* strip in which different strains were employed, although the species were sown in the same proportions, establishment differed markedly from the other areas. The total establishment was less dense, and ryegrass and cocksfoot were both considerably reduced, although timothy showed a much higher establishment.

(*b*) *The composition of the sward during the experiment.* After abundant tillering it was no longer possible to count individuals, and the composition was therefore determined in terms of percentage cover by the point method. This was done on two occasions, once at the beginning of the period of observation of the experimental animals (May 26, 1950); and once just after the end (November 3, 1950).

By the first date of sampling there had been considerable development of the sward, which had been grazed by dairy cows in 1949. In *A* and *Bi* the amount of ryegrass relative to the other species increased considerably, so that its cover was about four times greater than that of cocksfoot. Timothy had maintained a proportion about one-third that of cocksfoot, but the contribution of the clovers to the community had slightly increased, although still at a low level. Of the 'volunteer' species, rough-stalked meadow grass had greatly increased, now giving a cover considerably larger than that of cocksfoot. The meadow grass, however, tended to occupy a lower stratum in the community than ryegrass and cocksfoot, and was often recorded at the same sampling points as these two, lying below their shoots. Couch grass was frequently encountered.

In the *Bii* strip the ryegrass had not increased so much in proportion to the other species, but cocksfoot had increased to a level comparable with that in the other sections. Timothy maintained a level distinctly higher than in *A* and *Bi*; the clovers showed a markedly higher percentage cover than in the other sections.

The treatment received during the period of the experiment caused little change in the structure of the community, and the second date of sampling indicated only minor changes. The most noticeable differences common to *A* and *Bi* were a general fall in the representation of the 'volunteer' species, including rough-stalked meadow grass, which had dropped to about half the cover shown in May.

Changes in the Weed Population

Estimations of the density of the weed populations in the experimental area were made on three occasions by counting plants contained in a ¼ sq. metre quadrate sited as in the previous estimations (i.e. 10 samples per transect; 4 transects in *A* and *Bi*, 2 in *Bii*). Counts were made at the time of pasture establishment prior to grazing (June 28, 1949), later the same year after 12,000 hours of cow grazing per plot but before the experiment had begun (September 13, 1949), and finally after the experiment had been carried out with the application of 72,500 hours of cow grazing per plot (November 1, 1950). Thus the original weed

population was recorded, and populations at the beginning and end of the experiment, sampled at approximately the same time of year, were compared.

(*a*) *Weed populations at the time of pasture establishment.* At first the bulk of the population consisted of species characteristic of arable rather than pasture communities, and was uniformly spread throughout both plots.

(*b*) *Weed populations in established sward, prior to grazing.* There was a considerable change in the population, reflecting the development of the sward and the grazing treatment even in a period as short as 3 months. The arable species were greatly reduced, but there was an increase in the numbers of species typical of grassland. Plot *A* contained very few weeds, while *Bi*, and particularly *Bii*, showed an increasingly heavy infestation.

(*c*) *Weed populations at end of experiment.* The continued grazing changed the weed populations both in species and density, and the original species typical of arable conditions either disappeared or became reduced to insignificant proportions. There remained a simple population of typically grassland species. The differences between *A* and *B* were now very great. Plot *A* was virtually free from weeds, but there was still a large population in *B*—especially in *Bii*.

Weeds of hedge and bank in plot B.—Animals in plot *B* had access to the bank round two sides of the sector. Here the following species were recorded in abundance, *Anthriscus sylvestris*, *Cirsium arvense*, *Anthemis arvensis*, and *Plantago lanceolata*. Besides a variety of other common meadow plants which were present in smaller quantities, shrubs such as *Cytisus scoparius* and *Ulex europaeus* grew on this bank.

Observations on the Growth and Behaviour of the Grazing Animals
(*D. E. Tribe and J. G. Gordon*)

Experimental animals.—Twenty Ayrshire and two Red Poll heifer calves were paired and divided into two similar groups each of eleven animals on the basis of age, weight, previous history, and sire. The animals ranged in age from 9 to 15 months' old and were thus in an actively growing stage. It is generally assumed that the nutritional merit of browse lies in its mineral content [5], and, therefore, the use of young grazing cattle, whose mineral requirements are known to be high, should have been sufficient to demonstrate its value. The criterion of the nutritional efficiency of the two types of vegetation was the live-weight increase of the young cattle grazing them. All animals were weighed once each week throughout the experimental period.

Grazing management.—It was obviously necessary to keep the animals continuously on the experimental area for as long as possible. Fortunately the wet summer of 1950 was very suitable for the growth of grass, and pasture remained sufficiently productive until the end of August. On August 24 it was thought that the number of animals in each group was too large for the amount of herbage available and then each group was reduced from eleven to five animals. The experiment

terminated on October 26, 1950, when there was insufficient herbage to maintain a worthwhile comparison between the groups.

Behaviour recordings.—In order to determine whether there was any difference between the grazing behaviour of the two groups they were watched continuously for 96 hours in July 1950 and recordings made of the times devoted to grazing, idling, and resting. The observation

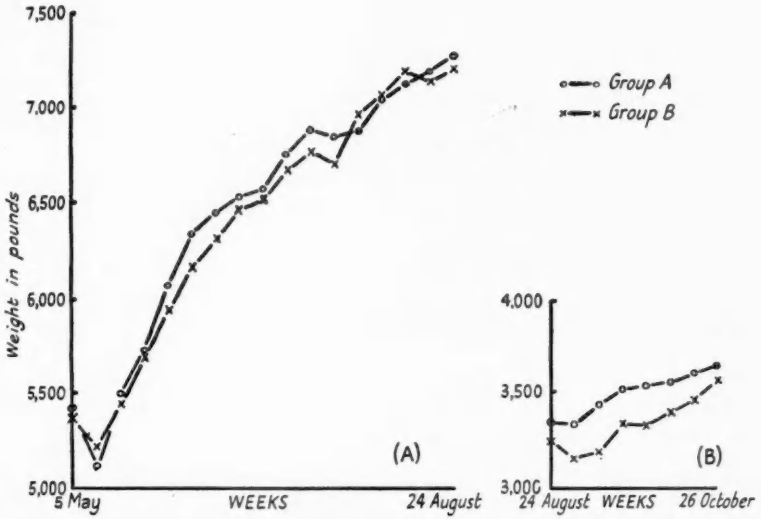

FIG. 1. (A) The total body-weight increases of each group (11 animals in each group) from May 5 to August 24, 1950. (B) The total body-weight increases of each group (5 animals in each group) from August 24 to October 26, 1950.

technique was as follows. At intervals of 5 minutes throughout the whole period of observation a record was made of the number of cattle in each group that were either grazing, idling, or resting. Grazing includes any activity involved in the selection, collection, and consumption of food; resting means actually lying down, and idling includes all other activities. The recordings were made by three observers who worked 8-hour shifts. The total time spent by one group on a certain activity during 24 hours was divided by eleven to give a figure which represents the average time spent by an individual on that activity during that time.

Results and Discussion

(*a*) *Body-weight increase.*—Fig. 1 represents graphically the total live-weight increase of the two groups from May 5, 1950, until October 26, 1950. From May 5 until August 24 there were eleven animals in each group and from August 24 until October 26 there were only five in each group.

These results make it clear that the presence of browse in plot *B* conferred no benefit in terms of live-weight increase upon the animals grazing it.

It will be realized that the system of management adopted to maintain a supply of browse in the herbage (plot *B*) involves a reduction in the potential production of digestible nutrients per acre. Both plots carried the same number of animals, but a considerable amount of forage was removed from plot *A* on the various occasions when topping by motor-scythe was carried out, whereas plot *B* was fully stocked. A greater production was thus obtained from the 'productive grass' plot than from the 'browse' plot, and unless it can be demonstrated that this is compensated for by the presence of some essential nutrient or balance of nutrients in 'browse' that is lacking from 'productive grass', it would be unwise to advise the adoption of such a scheme by farmers. The present experiment, carried out on land of high fertility, fails to demonstrate any such advantageous constituent in browse, though the possibility remains that some value might be shown under less favourable conditions.

It may be argued that had performance throughout pregnancy or lactation been employed as the criterion of nutritional efficiency a result in support of the 'browse theory' might have been obtained. This can only remain a matter for conjecture until such experiments have been carried out.

(*b*) *Grazing behaviour records.*—Hancock [6] has discussed the influence of the quantity and quality of herbage on grazing habits. He states that cows spend a longer time grazing when either the quality or quantity of a sward is poor than when both are optimal. He uses the customary definition of poor-quality herbage, i.e. mature, poorly digestible, fibrous material. In the present study, since the animals of group *B* were grazing herbage of very mixed quality, it might be expected that group *B* should spend a longer time grazing than group *A*. The results in Table 2 show that in fact group *B* grazed on the average for a little less time than group *A*. These observations conflict with the statement of Hancock [6] that 'if the quality is mixed the resulting grazing time becomes long . . . because the cows lose in efficiency of grazing as they try to select material of better quality'. To explain the variance in these results it is necessary to relate the quantity of herbage offered to its quality. If, as with group *B*, there is an abundance of herbage on offer the animals can quickly satisfy their appetite since the time spent in the collection of food is considerably reduced. In addition, as the quality is poor, and the dry-matter and fibre-contents high, it is quite conceivable that the animals reach satiation before they would have done had the quality been good. The idea that in a mixed sward animals will spend their time selecting the more luscious material has been found [1] to be erroneous. Our observations confirm that if young dairy stock have access to luscious as well as fibrous herbage they will graze from both types and not specialize on one or the other. Since, in general, the luscious herbage in plot *B* was located in section *Bi* and the coarser material in strip *Bii* and along the bank, the time spent in the selection

of the different types was not unusually great. We conclude that where, as in this experiment, the density of a sward is high and the quality mixed, the grazing times will be shorter or similar to that of cows grazing a sward in which both density and quality are high. If, however, the density and quality are poor then we suspect that grazing times would be lengthened. This view is supported by the results of Tayler [7], who found that grazing times were lengthened in winter when the quality of a sward deteriorated, for then the quantity decreased as well. However, in summer when the quality fell but the quantity remained high, the same effect was not observed. Jones [8] also found that sheep grazing a quantitatively good permanent pasture spent the same time grazing as sheep on a luscious temporary ley, but when on a rough, quantitatively poor, pasture, the grazing times were considerably longer.

TABLE 2. *The Grazing Behaviour of Both Groups throughout Four Consecutive 24-hour Periods*

Date	*Group A*						*Group B*					
	Grazing		*Idling*		*Resting*		*Grazing*		*Idling*		*Resting*	
(*July*)	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*
24	10	13	2	43	11	04	10	01	3	24	10	35
25	11	23	1	46	10	51	9	48	2	28	11	44
26	10	25	4	28	9	07	10	32	3	56	9	32
27	11	37	4	25	7	58	10	36	2	03	11	21
Average	10	54	3	20	9	46	10	14	2	59	10	47

In addition to these observations on times of grazing it was frequently noticed that the animals in group *A* extended their heads beneath the electric fence in order to reach plants in the neighbouring plot, even though there was sufficient available herbage in their own plot. The animals of group *B* did not behave in this manner, but it was found that in *both* groups there were soil patches where the animals licked ruts 2 inches deep in the ground. Whether such behaviour is of nutritional significance is not known.

Summary

1. This paper describes an experiment designed to find out if browse is of nutritional significance to young cattle grazing a temporary pasture.

2. Eleven young dairy animals grazed productive grass alone while a similar group of eleven grazed productive grass plus browse. The plots were grazed from May 5 to October 26, 1950.

3. Botanical observations made on the two pastures throughout the experiment show how the experimental management was successful in reducing the weed population in the productive grass to a minimum, whilst encouraging the weed-growth in the browse plot.

4. The body-weights of all the animals were recorded weekly. There was no significant difference between the gains of the two groups.

5. Recordings of grazing behaviour over a 96 hours' period show a similarity between the groups in the times devoted to grazing.

6. This experiment provides no evidence to support the opinion that it benefits grazing animals to have access to browse in addition to luscious herbage.

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RECENT TRENDS IN FERTILIZER PRACTICE IN ENGLAND AND WALES

PART I. THE NATIONAL POSITION

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Introduction

THE more general appreciation of the value of fertilizers and a growing understanding of their use have lead to great increases in fertilizer consumption in the United Kingdom during and since the war. It is the object of this paper to show how fertilizer practice for individual crops and on farms of different types changed between 1944–5 and 1950. In Part I a brief description is given of the surveys providing the information, and estimates are given, for districts of different farming types, of the changes in fertilizer consumption per acre of crops and grass which took place 1944 to 1950. The changes in the use of fertilizers on individual crops are also estimated for the country as a whole. In Part II the recent changes in fertilizer practice on cereals, root crops, and grassland, and the present manuring of these crops, are discussed in greater detail.

The need to know how farmers used their fertilizer supplies was first felt during the war, and surveys of fertilizer practice carried out in 1942 [1] and the following years, together with accumulated experimental evidence on crop responses [2], enabled priorities to be assigned to the needs of different crops and decisions to be taken on the optimum allocation of limited shipping space for importing feeding-stuffs and fertilizers. Further surveys were carried out in 1948 and 1950, and their results have already been reported on individually [3, 4, 5]. The field work of the surveys was organized in the provinces by the Advisory Chemists and carried out by members of their staffs, and the value of this work has been largely due to their continued co-operation and interest. Those responsible for the 1950 surveys were A. Blenkinsop, J. W. Blood, M. N. Nicholson, J. B. E. Patterson, T. W. Walker, J. Webber, and Rice Williams; and credit is also due to those chemists who enabled the survey work to be carried out in the earlier years.

Details of sampling methods used in fertilizer surveys are given in the individual reports, but as comparison of the results of these surveys provides most of the material presented in this paper a brief description of the method of sampling is given here. In any year the districts for survey were chosen so that the major farming types of the country were represented and the individual districts were reasonably homogeneous for soil type and type of farming. In each survey district farms were assigned to four groups according to their total acreage of crops and grass, and about ten or more farms were selected at random from each size-group. On each of these farms details of fertilizer practice were recorded for a random sample of one or two fields under each crop.

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Since fertilizer practice is found to vary greatly from one district to another, even when soil types and types of farming are similar, there has always been some conflict between two aims in the history of the survey. The survey of entirely new districts together with information already collected provides a wider basis of knowledge of fertilizer practice for the country as a whole, and the results for a new area are of particular value to the local advisory services. However, in order to obtain accurate information on trends in practice it is most desirable to resurvey the same districts and, if practicable, the same farms. During the earlier years of the survey the first of these purposes was of greatest importance, and it is for this reason that detailed information on the changes in fertilizer practice which took place between 1944 and 1950 is only available for the districts described in Table 1. More recently, as the

TABLE 1. *Districts Providing Information on Trends in Fertilizer Practice*

County and District	*Dates of survey*
Highly farmed arable districts (A_1)	
1. West Riding. Cash crop and dairying district of the West Riding lying to the east of the line Ripon–Leeds–Sheffield (Vale of York).	1944, 48, and 50
2. Shropshire. The eastern district of mainly arable farming with some dairying around Newport, Wellington, Shifnal, and Bridgnorth.	1944, 48, and 50
Other arable districts (A_2)	
3. Wiltshire. An area of corn, sheep, and dairying based on the chalklands of S. and E. Wiltshire.	1944, 50
Mainly dairying districts (D)	
4*a*. Shropshire. The dairy-farming area of the north of the county adjacent to 4*b*.	1944
4*b*. Cheshire. Dairy-farming area of S. and W. Cheshire excluding the Peckforton and Bickerton Hills.	1950
5*a*. Devonshire. The eastern part of the county around Honiton and Axminster, an extension of the dairying area of S. Somerset and NW. Dorset.	1945
5*b*. Dorset. The dairying district consisting of the whole of the county to the north of the chalk escarpment.	1950
Other grassland districts (G)	
6. Northumberland. An area of mixed farming between Morpeth and Corbridge.	1945, 50
7. Devonshire. The Culm Measures of mid- and north-Devon. This district lies to the west of Tiverton and is mainly engaged in sheep- and cattle-rearing, with some dairying.	1945, 49
8. Cardiganshire. The whole of the county. Apart from the western coastal area the county is primarily an upland district, but there is a good deal of dairying enterprise in addition to rearing.	1945, 50

general picture of fertilizer practice throughout the country has become reasonably well determined, greater importance has been attached to the determination of trends, and surveys now in progress will provide further valuable information on subsequent changes in fertilizer practice.

Mainly arable farming areas are represented by the Vale of York, E. Shropshire, and SE. Wiltshire. The first two of these are highly farmed arable areas, whilst in the Wiltshire district corn-growing predominates. Of the dairy-farming areas, SW. Cheshire and N. Dorset were surveyed in 1950 and are compared with adjoining areas in

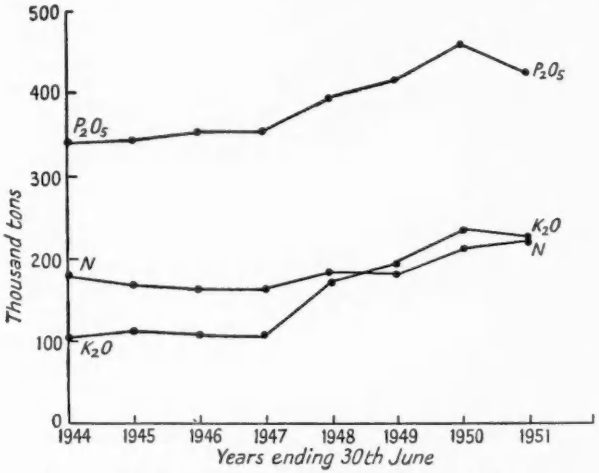

FIG. 1. Fertilizer consumption in the United Kingdom.

N. Shropshire and E. Devon, which were surveyed previously. Information on other predominantly grassland areas is obtained from the Morpeth–Corbridge district of Northumberland and from central Devon and Cardiganshire. Fertilizer practice surveys have been confined to England and Wales, and unfortunately in recent years it has not been possible, owing to acute shortage of staff, to carry out any surveys in East Anglia. In this paper, therefore, the discussion is generally confined to changes in fertilizer practice in England and Wales excluding the south and east, and the districts reported on are taken to represent that part of the country to the north and west of a line through The Wash and the Isle of Wight. This area includes about 55 per cent. of the tillage crops, 60 per cent. of the temporary grass, and 70 per cent. of the permanent grassland of England and Wales.

The National Position

Before discussing the changes in manuring of particular crops it is interesting to see how the fertilizer consumption of the whole country has changed in recent years. Fig. 1, based on data from the *Monthly*

Digest of Statistics [6], shows that there was little change in the use of fertilizers between 1944 and 1947, but between 1947 and 1950 potash consumption doubled, whilst the use of both nitrogen and phosphate increased by about a third. The sudden change in fertilizer use between 1947 and 1948 may have been partly due to the very late season in 1947, which restricted fertilizer applications in that year. Moreover, the figures in Fig. 1 are based on deliveries to merchants and farmers and may therefore differ appreciably from the amounts of fertilizers actually applied to the land in a particular year. Although they are not further discussed in this paper, the changes in fertilizer consumption between 1950 and 1951 are also shown in Fig. 1. On the basis of these data, phosphate consumption in the United Kingdom declined by about 10 per cent. in 1951, but nitrogen and potash consumption changed little from the 1950 level.

In Table 2 estimates are given from the survey data of fertilizer consumption per acre crops and grass for each of four farming types in England and Wales, excluding the south and east. The estimates for the different farming types, in this and in subsequent tables, are unweighted means of the corresponding figures for the individual survey districts listed in Table 1. In both the arable and the dairying districts nitrogen consumption is estimated to have increased by 0·07 cwt. N per acre between 1944 and 1950, whilst potash consumption increased by about 0·10 cwt. K_2O per acre. The general level of use of these nutrients and the increases since 1944 have been much smaller in the other grassland areas, but phosphate consumption appears to have increased by about 0·14 cwt. P_2O_5 per acre crops and grass in districts of all farming types.

TABLE 2. *Fertilizer Consumption in England and Wales excluding the South and East*

	1944			*1950*		
	cwt. per acre crops and grass					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Highly farmed arable districts . .	0·16	0·21	0·11	0·23	0·34	0·21
Other arable districts . . .	0·09	0·14	0·06	0·15	0·31	0·18
Mainly dairying districts . . .	0·05	0·17	0·03	0·12	0·30	0·14
Other grassland districts . . .	0·01	0·18	0·01	0·04	0·32	0·05
England and Wales excluding S. and E.	0·04	0·18	0·03	0·09	0·32	0·10
United Kingdom*	0·11	0·22	0·08	0·14	0·30	0·15

* Estimated from the fertilizer-consumption figures given in the *Monthly Digest of Statistics* [6].

At the bottom of the table the mean fertilizer consumption per acre of crops and grass in the whole of the region covered by the survey has been estimated by weighting the values for the four farming types according to the proportions of the total acreage which they represent.[1] The

[1] The weights used (1:1:2:6) were obtained by referring to the Types of Farming map of England and Wales [7] and using data from Table G of the report on the National Farm Survey [8]. Weights for individual crops have been similarly obtained, and have been used in the preparation of Table 3 and those subsequent tables which quote means over more than one of the four farming types.

corresponding figures for the United Kingdom, calculated from the data of Fig. 1, are shown for comparison: as mentioned above, these figures do not necessarily represent fertilizers actually applied to the land. The increases per acre in the use of phosphate and nitrogen appear to have been greater in the surveyed areas than in the United Kingdom as a whole, and taken at their face value the survey figures in Table 2 imply that nearly 90 per cent. of the increased consumption of these nutrients in the United Kingdom between 1944 and 1950 was taken up in England and Wales excluding the south and east. Although it is probable that this part of the country has accounted for more than its proportionate share of the increased consumption of nitrogen and phosphate fertilizers (for we shall see that much of the additional supply of these nutrients has been used on grassland), it is unlikely that it has done so to this extent. The districts from which the survey information has been drawn may therefore have experienced rather greater changes in use of fertilizers during the last five years than the areas which they have been taken to represent.

Manuring of individual crops.—The estimated average rates of application of fertilizers to different crops in England and Wales excluding the south and east are shown in Table 3 for 1944 and 1950. All leys which are down for less than seven years have been classified as temporary grass. In this and in subsequent tables the average dressing of any fertilizer component over all fields, including fields which are not dressed, is called the overall average rate of application; the average dressing over all fields which did receive the fertilizer component is called the average actual rate of application. The averages in Table 3 have been obtained by appropriately weighting[1] the estimates for the different farming types, which will be quoted separately for some of the crops in Part II of this paper. Since the estimates are based on only eight survey districts they may differ appreciably from the true average figures, but they do show quite clearly a number of interesting facts regarding the increase in use of fertilizers.

TABLE 3. *Overall Average Rates of Application of Fertilizers in England and Wales excluding the South and East, 1944–5 and 1950*

	1944 *cwt. per acre*			*1950* *cwt. per acre*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat and barley	0·08	0·32	0·04	0·12	0·32	0·13
Oats and mixed corn	0·06	0·29	0·01	0·08	0·28	0·12
Potatoes	0·43	0·61	0·64	0·70	0·81	0·98
Mangolds	0·26	0·60	0·14	0·40	0·58	0·55
Swedes and turnips	0·18	0·56	0·07	0·22	0·67	0·22
Kale	0·31	0·44	0·13	0·26	0·50	0·31
Temporary grass	0·03	0·10	0·01	0·09	0·44	0·08
Permanent grass	0·01	0·09	0·01	0·05	0·25	0·04

[1] See footnote on p. 252.

Evidently there have been increases in the use of both nitrogen and potash on all crops since 1944, and phosphate consumption has increased generally except on the cereals. Amongst the root crops the increases per acre in the use of all three nutrients have been greatest on potatoes, which were, of course, the most heavily manured root crop in 1944. The proportionate increases in the use of fertilizers on grassland have been very great, and in 1950 the grassland received fertilizers at average rates which compared favourably with those to cereals in 1944.

It is also interesting to see how the total supply of fertilizers is distributed between the various crops and to what extent this distribution has changed. As may be seen from Table 4 the chief change in the cropping of the surveyed region of England and Wales between 1944 and 1950 was the doubling of the proportion of the total acreage which was under temporary grass. This increase of the temporary grassland acreage was at the expense of the permanent grass, and the proportion of the total acreage which was under tillage crops remained substantially unchanged at about 35 per cent., of which rather more than two-thirds was under cereals.

TABLE 4. *Estimated Percentages of the Total Fertilizer Supplies used on Different Crops in England and Wales excluding the South and East*

	1944				*1950*			
	Percentage of acreage under crop	N	P_2O_5	K_2O	*Percentage of acreage under crop*	N	P_2O_5	K_2O
Cereals . .	24	30	38	13	23	21	20	23
Potatoes . .	3	23	10	50	3	19	7	24
Fodder crops .	5	23	14	14	4	11	7	12
Other tillage .	2	9	6	6	5	13	9	15
Temporary grass	7	4	4	6	15	12	20	10
Permanent grass	59	11	28	15	50	24	37	16

The grassland received about a third of the phosphate supplies and a sixth of the nitrogen and potash in 1944. By 1950 these proportions had roughly doubled, and in that year grassland is estimated to have received 36 per cent. of the nitrogen, 57 per cent. of the phosphate, and 26 per cent. of the potash. It is remarkable that of the total increase in fertilizer consumption in 1950 above the 1944 level, about a third of the potash, 60 per cent. of the nitrogen, and nearly all the phosphate was used on grassland.

Sixty per cent. of the potash applied to tillage crops in 1944, when supplies were very limited, was used on the potato acreage, but the nutrient has since become much more generally used on other crops, and in 1950 about a third of the supplies to tillage were used on cereals. Cereals received a similar proportion of the nitrogen in 1950, and although the proportion of total phosphate supplies used on these crops had declined somewhat they accounted for nearly half of the supply to tillage in that year.

During the period under review there may have been considerable changes in the types as well as in the quantities of fertilizers used on particular crops. Some information on the types of nitrogen and phosphatic fertilizer used in 1950 has been published elsewhere [9], but comparable data are not readily available from the earlier surveys. The following figures, derived from the *Monthly Digest of Statistics* [6], show that there has been some increase since 1945 in the proportion of phosphate used in the form of basic slag and ground phosphate, at the expense of organic fertilizers and concentrated compound fertilizers, whilst superphosphate applied direct or in ordinary compound fertilizers has continued to account for just over half the total phosphate consumption:

	Percentage of total phosphate applied as			
	Super-phosphate	*Ground basic slag*	*Ground phosphate*	*All other fertilizers**
1944–5 . .	54	20	6	20
1949–50 . .	54	26	12	8

* Organic fertilizers, treated phosphate rock, and concentrated compound fertilizers.

As may be seen from Table 5 the survey data confirm that there was little change during the period under consideration in the proportion of phosphate applied to different crops in soluble form, and examination of figures for individual surveyed districts suggests that the only real and consistent change was a marked reduction in the proportion of total phosphate which was applied to cereals in the poorer grassland districts as basic slag. The table does, however, show a marked association between farming type and the proportions of soluble phosphate used.

TABLE 5. *Superphosphate* as a Percentage of the Total Phosphate Applied to Different Crops*

	Mainly arable districts		*Mainly dairying districts*		*Other grassland districts*	
	1944	*1950*	*1944*	*1950*	*1944*	*1950*
Cereals . . .	83	85	77	70	39	61
Roots . . .	94	95	95	76	52	56
Temporary grass .	59	55	42	38	..	11
Permanent grass . .	44	58	30	44	..	16

* Superphosphate as a straight fertilizer or in compounds.

In the arable and dairying districts nearly all the phosphate used on root crops and most of that applied to cereals is soluble; between a half and a third of the phosphate used on these crops in other grassland areas is in the form of slag or rock phosphate. The differences between farming types are similar on the grassland, where about half the

phosphate used in the arable and dairying districts is superphosphate compared with a very small proportion in other grassland areas.

Only in Northumberland and in N. Dorset amongst the districts surveyed in 1950 was the use of rock phosphate of any importance, and even there it was largely confined to the grassland. In both these districts 16 per cent. of the phosphate used on temporary grass, and in Northumberland about a third of that used on permanent grass, was rock phosphate.

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ADDENDA to Figures 4, 5, and 9 on Plates 7 and 9, Volume XIX.

M. Greenwood's paper on Fertilizer Trials with Groundnuts in Northern Nigeria in Volume XIX, No. 76, October 1951. The missing treatments, reading from left to right, are:

Fig. 4: (1) 50 lb. S/A, (2) 50 lb. S/A+50 lb. gypsum, (3) 50 lb. S/A+40 lb. NaH_2PO_4, (4) 50 lb. gypsum+40 lb. NaH_2PO_4.

Fig. 5: (1) No manure, (2) 25 lb. S/A, (3) 25 lb. gypsum, (4) 20 lb. NaH_2PO_4.

Fig. 9: (1) No manure, (2) 800 lb. bone-ash, (3) 50 lb. 'Super', (4) 100 lb. 'Super', (5) 200 lb. 'Super'.

RECENT TRENDS IN FERTILIZER PRACTICE IN ENGLAND AND WALES

PART II. THE USE OF FERTILIZERS ON CEREALS, ROOT CROPS, AND GRASSLAND

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IN the first part of this paper [1] the general character of the changes between 1944 and 1950 in farmers' use of fertilizers was discussed. Most of the data presented were based on the results of surveys carried out in eight districts of England and Wales in 1944–5 and in 1950, and the farming types of these areas were briefly described. In the following pages a summary is presented of the further information from these surveys on the manuring of cereals, root crops, and grassland.

The Use of Fertilizers on Cereals

The chief change in the manuring of cereals between 1944 and 1950 was a considerable increase in the use of nitrogen and potash. Throughout this period the use of phosphate on cereals in England and Wales excluding the south and east appears to have remained comparatively unchanged at about 0·30 cwt. P_2O_5 per acre, but nitrogen consumption increased by about a third to 0·10 cwt. N per acre while potash consumption rose to an average of 0·12 cwt. K_2O per acre from a very low level. Increases in fertilizer consumption were greatest on wheat and barley, and these crops received considerably more nitrogen and potash per acre in 1950 than did oats and mixed corn. However, a greater proportion of the wheat and barley is grown in the better arable districts, and in general rather similar proportions of the two groups of cereals were dressed within districts of any particular farming type in 1950, and parallel changes have taken place in their manuring since 1944 as may be seen from Fig. 1.

There has been a large increase, from practically nothing in 1944, in the proportions of cereals in grassland districts which receive nitrogen, though even in 1950 only about a quarter of the crop in these areas was dressed. In most other areas, where nitrogen has always been more generally applied and about half of the crop was dressed in 1950, the change since 1944 has been smaller. Amongst the surveyed districts only in SE. Wiltshire, where corn-growing predominates and the soils are rather poor, did the greater part of the cereal crop receive nitrogen, and even there about a fifth of the acreage had no dressing in 1950. Clearly, at least half of the cereals grown outside East Anglia and SE. England had no nitrogen dressing in 1950, and a more general use of this nutrient

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on cereals in all except the wettest upland districts would certainly give valuable increases in production [2].

In most districts the proportion of the cereal acreage receiving phosphate did not change much between 1944 and 1950. During the war the use of potash was confined to markedly deficient soils, and much more of the cereal acreage in all areas now receives this nutrient. There is a striking contrast between the very potash-deficient district of Wiltshire where most of the cereals received potash in 1950, and the other surveyed areas where on the average about a quarter of the crop was dressed.

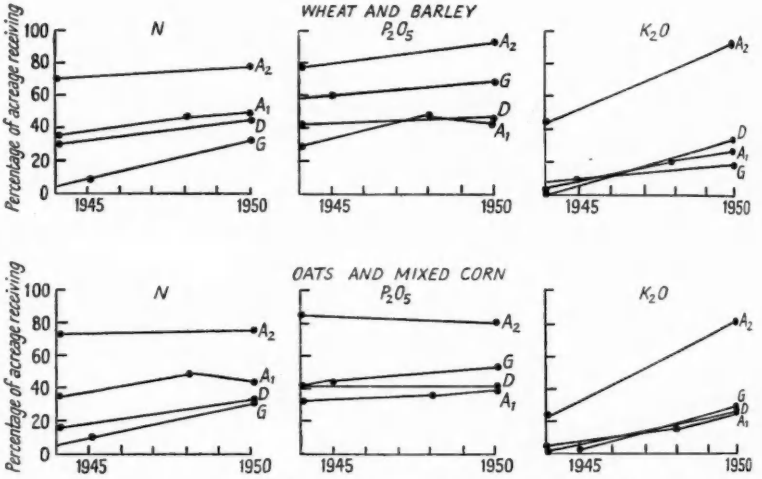

FIG. 1. Trends in the proportions of the cereal acreage receiving fertilizers in districts of different farming types.

A_1 = highly farmed arable districts
A_2 = other arable districts
D = dairying districts
G = other grassland districts

The districts representing these farming types are those listed in Table 1 of Part I of this paper.

When nitrogen or potash is used on cereals the average dressings are fairly similar for all farming types, but nitrogen dressings are heavier in some of the more highly-farmed arable districts like the Vale of York, and in some other areas, for example N. Dorset and N. Buckinghamshire, average dressings are less than 0·20 cwt. N per acre. Phosphate dressings, as may be seen in Table 1, are heavier in the grassland districts where more of this nutrient is applied in the form of basic slag.

The most notable change since 1944 in the average actual dressings to cereals is the decline in rates of application of phosphate in nearly all districts. The decrease was greatest in the better arable and dairying districts and may be largely due to the increased use of compound

fertilizers. Since average actual dressings to the four cereal crops are generally very similar in any district, the figures shown in Table 1 are the means of those for the individual crops. Average applications in 1950 to wheat and barley, and to oats and mixed corn are compared below:

	Average actual dressings cwt. per acre		
	N	P_2O_5	K_2O
Wheat and barley . . .	0·25	0·50	0·34
Oats and mixed corn . .	0·24	0·55	0·38

TABLE 1. *Average Actual Rates of Application of Fertilizers to Cereals in England and Wales, excluding the South and East*

	1944 cwt. per acre			*1950 cwt. per acre*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Mainly arable districts .	0·24	0·50	0·32	0·26	0·38	0·34
Mainly dairying districts	0·26	0·67	..	0·23	0·55	0·35
Other grassland districts	0·25	0·68	..	0·23	0·65	0·40

The average nitrogen application to cereals, which has hardly changed since 1944, is low, though not unduly so for districts with a heavy rainfall. In nearly all districts, however, there are some farmers using nitrogen at rates of 0·20 cwt. N per acre on cereals, or even less, and in some areas, particularly perhaps in the Midland counties, a general increase in nitrogen dressings would be profitable, especially if the newer stiff-strawed cereal varieties were grown. The average dressings of phosphate and potash to cereals appear to be heavy by comparison with the most profitable dressings, which were estimated by Crowther and Yates [3] to be 0·24 cwt. P_2O_5 per acre and 0·05 cwt. K_2O per acre (broadcast in the seed-bed) in the west Midlands and northern England at 1940 prices. Owing to the considerable changes in price structure the most profitable dressings in 1950 were heavier (about 0·4 cwt. P_2O_5 and 0·3 cwt. K_2O per acre) but subsequent price changes have again reduced these values, and it is clear that phosphate and potash have tended to be applied in uneconomic quantities to cereals, and particularly to crops grown after well-manured roots, which generally need no dressing of these nutrients. At the prices of February 1952,[1] 0·2 cwt. K_2O per acre was about the optimum dressing on average soil and, except possibly in the south-west and in Wales and Scotland, the optimum phosphate dressing was generally no more than 0·1 cwt. P_2O_5 per acre.

On the average in 1950 second cereal crops were more frequently dressed than cereals grown after other crops, but the actual dressings when nutrients were applied were similar, as may be seen from Table 2. The figures quoted in the table are the unweighted means of those for

[1] Superphosphate (18%) at 10*s.* 6*d.* per cwt. and muriate of potash (50%) at 18*s.* per cwt. to the farmer.

TABLE 2. *The Influence of Previous Cropping on the Manuring of Cereals in 1950*

	Percentage of acreage receiving			*Average actual rates cwt. per acre*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Previous crop						
Cereals . . .	44	54	32	0·25	0·66	0·34
Other crops . .	28	34	16	0·24	0·54	0·38

the individual survey districts. It is, however, clear from the following figures for actual rates of application to cereals in the Vale of York (1950) that in some of the better arable areas the actual dressings to cereals are reduced somewhat when roots have been previously grown:

	Average actual dressings cwt. per acre		
Previous crop	N	P_2O_5	K_2O
Cereals . . .	0·33	0·48	0·37
Roots . . .	0·24	0·33	0·23

Although on most soils it is unlikely that the residual value of nitrogen applied in the previous year will be very great, nitrogen dressings to cereals grown after roots appear to be reduced in proportion to the dressings of the other fertilizer constituents.

Except on very poor land autumn dressings of nitrogen are usually regarded as wasteful since the amount of nitrate nitrogen present in the soil is already high at this time of year, and any additional nitrogen fertilizer applied is likely to be leached out during the winter months. Such experimental data as exist seem to confirm this view. When nitrogen is applied in autumn, there is every reason to regard this as merely supplementary to the normal spring top-dressing; however, as will be seen from Table 3, much of the winter cereals which received nitrogen in the 1949–50 crop-year had only an autumn dressing. In the cereal-growing district of SE. Wiltshire in particular, less than a fifth of the winter cereals received a top-dressing of nitrogen and some 60 per cent. of the crop received dressings in the autumn. There is also a tendency in some districts to top-dress cereals with complete fertilizers in the spring. Thus in 1950 a third of the acreage of winter cereals in the Vale of York which received nitrogen as a top-dressing also received phosphate at the same time. Phosphate or potash so applied is unlikely to become fully available to the plant, and it is also doubtful whether much of these nutrients would be taken up by winter cereals at this stage of their growth. Thus, as is also shown in Table 3, apart from the fact that dressings of phosphate and potash to cereals are frequently too high, perhaps a fifth of the applications are wasteful because they are not made in the seed-bed.

TABLE 3. *The Use of Nitrogen on Winter Cereals and the Proportions of the Total Phosphate and Potash applied to all Cereals in 1950 that were top-dressed*

	Percentage of acreage of winter cereals receiving nitrogen			*Top-dressings to cereals as percentage of total dressings*	
	In seed-bed only	*Top-dressed only*	*Both*	P_2O_5	K_2O
Highly-farmed arable districts	21	28	8	17	18
Other arable districts . .	49	7	10	2	2
Mainly dairying districts .	8	26	14	29	29
Other grassland districts .	16	16	12	18	11

The amounts and types of fertilizers used on cereals have probably been influenced to some extent by the increasing use of the combine drill. Combine-drilling leads to a much more efficient use of nutrients, and rather smaller dressings are therefore adequate when this method is used. This practice, which was first introduced in the south and east of England has now spread to other parts of the country. Of the districts surveyed in 1950, combine-drilling of cereals is now almost universal in SE. Wiltshire and is general in Dorset. The surveys indicate that about a third of the cereal crop in E. Shropshire which received phosphate and about a fifth of that in the Vale of York was combine-drilled in 1950; and it is of particular interest that half the cereals receiving phosphate in a district as far north as Northumberland were combine-drilled in that year.

Giving equal weight to the results from each surveyed district, the average fertilizer applications in the seed-bed, over all fields which received any fertilizers in the seed-bed in 1950, were as follows:

	cwt. per acre		
	N	P_2O_5	K_2O
Cereals receiving fertilizers combine-drilled	0·12	0·41	0·16
Cereals receiving fertilizers broadcast . .	0·10	0·71	0·16

Virtually all the cereals dressed received phosphate in the seed-bed, and average phosphate dressings were considerably lower on combine-drilled fields. As has been shown elsewhere [4], average actual dressings of nitrogen and potash are also much lower on combine-drilled fields, but about 80 per cent. of the combine-drilled acreage received some nitrogen in the seed-bed, compared with little more than half the acreage on which fertilizers were broadcast. Thus, although combine drilling does effect a substantial saving in phosphate fertilizers, on the average about equal amounts of nitrogen per acre appear to be applied in the seed-bed on combine-drilled fields and on fields receiving fertilizers broadcast. From the limited data available it seems that the subsequent top-dressing of cereals varies little with the method of fertilizer application in the seed-bed. About a fifth of the cereals which received no fertilizer in the

seed-bed in 1950 were top-dressed, and about 10 per cent. of the cereals received both an initial fertilizer application and a top-dressing.

The Manuring of Root Crops

We have already seen that potatoes are the most heavily manured of the root crops and that there have been substantial increases in the use of fertilizers on potatoes since 1944. Table 4 shows for the surveyed areas the proportions of the potato acreage receiving fertilizers and the average actual rates of application, for mainly arable districts and grassland districts separately. The table shows that in the arable areas nearly all the potato crop received complete fertilizers in 1944, and in addition rather more than half of the crop in these areas received F.Y.M. Thus in these districts, where the crop is now generally well manured, the increases since 1944 in the use of fertilizers on potatoes were largely due to

TABLE 4. *The Manuring of Potatoes in England and Wales excluding the South and East*

		Percentage of acreage dressed		*Average actual rates (cwt./acre)*	
		1944	*1950*	*1944*	*1950*
Mainly arable districts	F.Y.M. . .	62	60	..	..
	N . .	94	98	0·69	0·98
	P_2O_5 . .	98	99	0·71	1·04
	K_2O . .	95	96	0·93	1·42
Mainly grassland districts	F.Y.M. . .	82	75	..	..
	N . .	62	78	0·43	0·62
	P_2O_5 . .	79	83	0·66	0·76
	K_2O . .	58	76	0·72	0·90

the much heavier average fertilizer dressings: in 1950 average dressings were nearly 50 per cent. greater than in 1944. In the grassland districts there was a marked increase between 1944 and 1950 in the proportions of the potato acreage receiving nitrogen and potash, but even in the latter year about a fifth of the crop in these areas received no nitrogen fertilizer. The average actual rates at which all three nutrients were used also increased substantially in these areas, and the general levels of application in 1950 were similar to those of the arable districts in 1944. Actual rates of application of F.Y.M. to potatoes in 1950 were about 15 tons per acre in most districts, but were estimated to be more than twice this in the dairying district of SW. Cheshire.

Some additional information on the manuring of potatoes is available from the 1948–50 surveys of maincrop potatoes [5]. These surveys covered most of the counties of England and Wales and the estimates are therefore broadly based. Table 5 compares the manuring of potatoes in 1950 in E. and SE. England with their average treatment in the rest of the country. The comparable estimates from the Survey of Fertilizer Practice are also given and there is substantial agreement between the results of the two surveys. The fertilizer survey estimates of the average

TABLE 5. *The Manuring of Potatoes in 1950*

	Percentage of acreage receiving				*Average actual rates*			
	F.Y.M.	N	P	K	F.Y.M. *tons/ acre*	N	P_2O_5 *cwt./ acre*	K_2O
Potato Survey data:								
E. and SE. England	49	96	95	92	13	0·87	0·97	1·30
Rest of England and Wales	76	91	93	91	15	0·81	0·91	1·12
Fertilizer Survey data:								
Rest of England and Wales	69	86	90	84	17	0·77	0·87	1·11

use of fertilizers on potatoes outside the eastern counties are rather lower, but they are based on the total potato acreage, including first and second earlies which were excluded from the potato survey. The figures once again emphasize the fact that on the average the potato crop is well manured, and indicate that rather more fertilizer per acre is being used on this crop in the eastern counties, where supplies of F.Y.M. are limited and only half the potatoes are dunged. However, there is evidence from both surveys that in some of the poorer grassland districts, where potatoes are not an important cash crop, the manuring on many farms is in some respects far from adequate. Thus in both Cardiganshire and Montgomery less than half the crop received any nitrogen dressing, and when nitrogen was used the average dressings were small. The fact that much of the crop in these districts did not receive phosphate and potash is probably less serious, since fairly heavy dressings of F.Y.M. were given. The potato survey showed that it is in districts of this kind that late planting and the use of inferior seed occur, and experiments carried out at Rothamsted suggest that responses of potatoes to F.Y.M. and fertilizers are reduced substantially, perhaps by a factor of two, when the crop is planted late. In order to obtain the full return for increased use of fertilizers on potatoes in these districts it would be necessary for the general standard of their farming to be improved.

Even in 1950 in the mainly arable-farming districts fertilizer applications to potatoes were somewhat below the estimated optimum rates at 1949–50 prices, which were about 1·2 cwt. N, 1·4 cwt. P_2O_5, and 1·5 cwt. K_2O per acre, allowing for the proportion of the crop acreage receiving F.Y.M. However, the manuring in these areas was at a level giving a good return to the farmer and very close to the optimum at present (1952) prices.

As far as can be judged the individual farmer does not modify his use of fertilizers on potatoes, or indeed on other crops, when F.Y.M. is applied. However, even within a fairly homogeneous district, it is clear that on the whole less fertilizers are used on potatoes and on other crops on farms where a liberal supply of F.Y.M. is available.

The results of the potato survey indicate that there was virtually no change between 1948 and 1950 in the proportion of the potato crop in

England and Wales receiving fertilizers. About 93 per cent. received some nitrogen dressing, whilst 94 per cent. received phosphate and 82 per cent. of the crop received potash. However, during this period there has been a small increase in the average actual rates at which the nutrients have been applied, particularly outside the eastern counties, as may be seen from Fig. 2. In E. and SE. England average dressings were highest in 1949, only the average rates of potash application being maintained at the same level in 1950, but in the rest of the country the increase in average use of potash was slight but continuing during these three years, whilst average nitrogen and phosphate dressings increased between 1948 and 1949 and were maintained in 1950.

FIG. 2. Changes in average actual dressings to potatoes 1948–50. Data from the Survey of Maincrop Potatoes (5)

Sugar-beet is manured similarly to potatoes where both crops are grown, but the crop is not nearly so widely grown outside the eastern counties, and amongst the districts surveyed only E. Shropshire and the Vale of York grew an appreciable acreage. The average manuring of sugar-beet in these districts is shown in Table 6. The most striking change in practice since 1945 is the doubling of the rate at which potash is applied to the crop.

Since about half the sugar-beet also received F.Y.M., and, in addition to the standard nutrients, a few of the sampled fields in the Vale of York and about two-thirds of the sugar-beet in E. Shropshire received dressings of salt at an average rate of about $4\frac{1}{2}$ cwt. per acre, the heavy potash applications on many of the fields would seem to be rather extravagant, for sugar-beet does not generally respond well to large dressings of this nutrient particularly when salt and F.Y.M. are also used: however, the soils of both E. Shropshire and the Vale of York are particularly responsive to potash. The most profitable dressings for sugar-beet grown on

average soils at the favourable prices of 1949–50 are estimated to have been about 0·9 cwt. N, 0·7 cwt. P_2O_5, and 0·6 cwt. K_2O per acre when F.Y.M. was also used.

TABLE 6. *The Manuring of Sugar-beet in England and Wales excluding the South and East*

	Percentage of acreage dressed		*Average actual rates (cwt./acre)*	
	1945	*1950*	*1945*	*1950*
F.Y.M. . .	40	52	..	..
N . . .	91	94	0·80	0·96
P_2O_5 . . .	87	98	0·80	0·94
K_2O . . .	86	90	0·66	1·22
Salt . . .	..	56	..	4·40

Estimates of how fertilizer consumption on mangolds has changed in districts of different farming types are given in Fig. 3. Bearing in mind the errors in determination of the figures, it would appear that there were

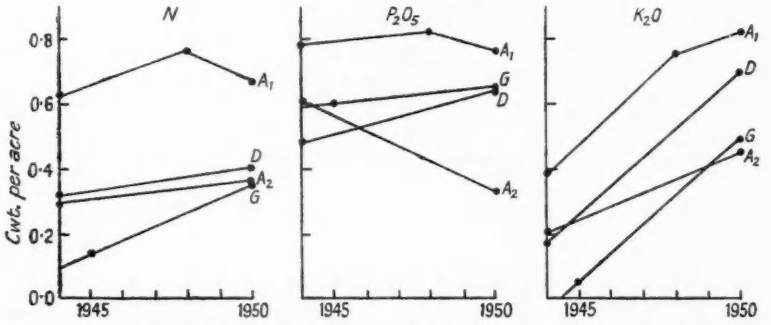

FIG. 3. Trends in the manuring of mangolds in districts of different farming types. Overall rates of application cwt. per acre. (See Fig. 1.)

only slight changes in the use of nitrogen and phosphate on the crop between 1944 and 1950 in most districts, though nitrogen consumption on mangolds in the poorer grassland districts doubled during this period, and the crop is now similarly manured in all districts outside the highly-farmed arable areas. The use of potash on mangolds more than doubled in most districts between 1944 and 1950, whilst in the poorer grassland districts where hardly any of the nutrient was used in 1944 consumption rose to about 0·5 cwt. K_2O per acre in 1950. The apparent large decline in use of phosphate in the Wiltshire district may be due to sampling error, though some decline may have accompanied a more general use of complete fertilizers.

The changes in the average manuring of fodder root-crops and kale between 1944 and 1950 are summarized in Table 7. The figures for swedes and turnips and for kale are not accurately determined

owing to the small numbers of fields under these crops which were included in the sample in most of the surveyed districts; moreover, fertilizer practice is particularly variable on these crops since it depends on their utilization. The proportion of mangolds receiving nitrogen has increased from rather more than half in 1944 to about 70 per cent., but only half the swedes and turnips received nitrogen in 1950 and the proportion of the kale crop receiving this nutrient, though not well determined, may even have declined since 1944. There have been large increases in the proportions of all these crops receiving potash since 1944 and in 1950 they were much the same as the proportions receiving nitrogen. On mangolds, and swedes and turnips, average dressings of potash increased considerably during this period and were at a reasonable level in 1950, though possibly still rather less than the most profitable dressings at the favourable 1949–50 prices. It should, however, be noted that in E. Shropshire in 1950 some 60 per cent. of the mangold acreage received salt at an average rate of 4½ cwt. per acre in addition to normal nutrients.

TABLE 7. *The Manuring of Fodder Roots and Kale in England and Wales excluding the South and East*

	Percentage of acreage dressed		*Average actual rates (cwt./acre)*	
	1944	*1950*	*1944*	*1950*
Mangolds				
F.Y.M.	83	81	..	..
N	55	71	0·46	0·52
P_2O_5	86	75	0·69	0·71
K_2O	29	66	0·48	0·84
Swedes and Turnips				
F.Y.M.	55	58	..	..
N	48	51	0·35	0·42
P_2O_5	83	77	0·69	0·92
K_2O	17	40	0·39	0·57
Kale				
F.Y.M.	50	59	..	..
N	80	58	0·39	0·44
P_2O_5	76	83	0·57	0·63
K_2O	35	57	0·51	0·53

Since considerable proportions of the acreages of fodder roots still receive no nitrogen fertilizer, and average nitrogen dressings to these crops are about half the optimum, production of fodder roots could be substantially increased by the use of more nitrogen. It is estimated that if all mangolds, and swedes and turnips received 2½ cwt. per acre of sulphate of ammonia, the total yield of mangolds outside the eastern counties might be increased by about 8 per cent., and that of swedes and turnips by 13 per cent. Kale would also certainly give good returns for much heavier nitrogen dressings than those usually given.

The Use of Fertilizers on Grassland

Until very recently the total fertilizer consumption of the country was largely determined by the amounts applied to the tillage acreage. Since the end of the war, however, and especially during the last two or three years, the amount of fertilizer applied to grassland has increased greatly. Indeed, as was shown in the first part of this paper, much of the increase in fertilizer supplies since 1944 has been used on the grass. The trends in fertilizer consumption per acre of temporary and permanent grass between 1944 and 1950 are shown in Table 8 for the different farming types of England and Wales excluding the south and east. For the purposes of the survey, fields down to grass for more than seven years have been classified as permanent grassland.

On temporary grassland in the arable and dairying districts fertilizer consumption increased by an average of about 0·12 cwt. N, 0·34 cwt. P_2O_5, and 0·12 cwt. K_2O per acre. The increases per acre of permanent

TABLE 8. *The Use of Fertilizers on Grassland in England and Wales excluding the South and East*

		cwt. per acre					
		Temporary grass			*Permanent grass*		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
Highly-farmed arable districts	1944	0·06	0·14	0·01	0·02	0·05	0·00
	1950	0·21	0·44	0·12	0·10	0·23	0·05
Other arable districts	1944	0·05	0·03	0·02	0·02	0·02	0·00
	1950	0·14	0·43	0·11	0·08	0·23	0·05
Mainly dairying districts	1944	0·06	0·12	0·02	0·02	0·10	0·02
	1950	0·19	0·44	0·16	0·10	0·29	0·12
Other grassland districts	1944	0·01	0·11	0·00	0·00	0·10	0·01
	1950	0·03	0·45	0·04	0·01	0·23	0·01

grass in these districts between 1944 and 1950 were smaller, being rather more than half the above figures. On both temporary and permanent grass in the other grassland districts comparable increases in phosphate consumption took place but the increases per acre in the use of nitrogen and potash were very much smaller.

The changes in the proportions of temporary and permanent grass which received fertilizers are shown in Fig. 4 for four farming types separately. The proportions of both temporary and permanent grassland which received fertilizers were remarkably similar throughout this period in the arable and dairying districts. About 55 per cent. of the temporary grass and 35 per cent. of the permanent grass received nitrogen, and similar proportions received phosphate in 1950 compared with 30 per cent. and 15 per cent. respectively in 1944. During the same period the proportion of grassland in these districts which received potash increased from practically zero to about a third of the temporary grass and a sixth of the permanent grass.

Except for the more widespread use of phosphate on temporary grass, the increases in the proportions of grassland receiving fertilizers in the other districts were much smaller, so that the contrast between the manuring of grass in the arable and dairying districts and elsewhere has increased greatly. Even in 1950 only about a sixth of the temporary grass and 5 per cent. of the permanent grass in the poorer grassland districts received any fertilizer other than phosphate, and it therefore appears that there is still great scope for increased grass production by the more widespread use of nitrogen, even at rates of application of about 1 cwt. sulphate of ammonia per acre. However, the value of such fertilizer application is, of course, completely dependent on the proper utilization of the additional sward produced. There was difficulty in obtaining basic slag in some grassland areas in 1950, particularly in Cardiganshire, among the districts surveyed, and possibly phosphate would have been rather more widely applied to the grassland had it been readily available.

Although we do not know for all districts whether the very large increases in the proportions of grassland dressed took place steadily between 1944 and 1950, information from the 1948 surveys in E. Shropshire and the Vale of York shows that in the better arable areas the increases certainly continued since then, and the national consumption figures suggest that the same is true elsewhere.

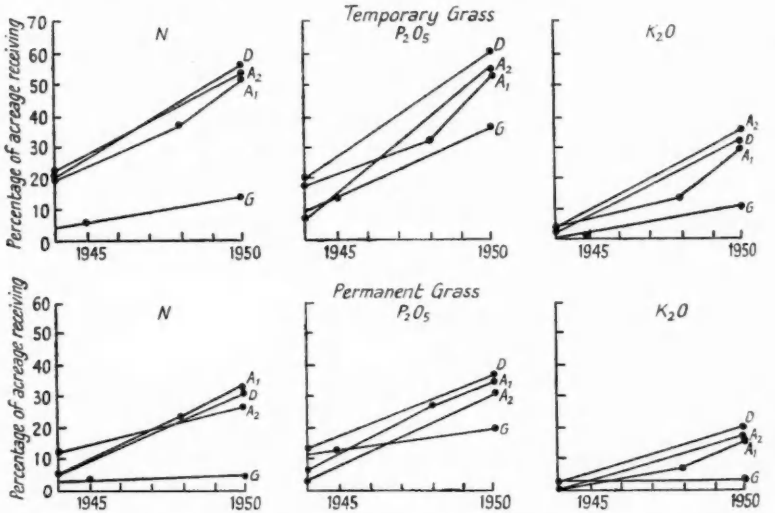

FIG. 4. Trends in the proportions of grassland receiving fertilizers in districts of different farming types. (See Fig. 1.)

In addition to the increased proportions of the acreage receiving fertilizers, the average actual rates at which nutrients were applied to grass changed between 1944 and 1950 (see Table 9). Outside the dairy farming districts, where dressings were heavier than elsewhere in 1944,

nitrogen dressings on temporary grass generally increased by about 40 per cent. Actual rates of application of nitrogen to permanent grass were particularly low in SE. Wiltshire and the poorer grassland districts surveyed in 1944, and, although these rates had substantially increased by 1950, they were still lower than those in the better arable and dairying districts. Phosphate dressings increased, except in the highly-farmed arable districts, and they almost doubled in the poorer grassland districts between 1944 and 1950, when average dressings to temporary and permanent grass in these areas were about 1·2 cwt. P_2O_5 per acre. It would probably be better practice in many cases to dress more of the grassland acreage at lower rates, or alternatively to give smaller dressings more frequently, rather than to give such heavy phosphate dressings, especially when supplies are restricted.

TABLE 9. *Average Actual Rates of Application of Fertilizers to Grassland in England and Wales excluding the South and East*

		Temporary grass			*Permanent grass*		
		cwt. per acre			*cwt. per acre*		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
Highly-farmed arable districts	1944	0·27	0·82	(0·60)	0·29	1·10	..
	1948	0·36	0·88	0·50	0·28	0·80	0·34
	1950	0·39	0·82	0·46	0·31	0·68	0·32
Other arable districts	1944	0·20	0·40	(0·74)	0·18	0·62	..
	1950	0·27	0·78	0·30	0·28	0·70	0·30
Mainly dairying districts	1944	0·30	0·64	(1·20)	0·33	0·69	(1·50)
	1950	0·34	0·72	0·48	0·28	0·77	0·52
Other grassland districts	1945	0·16	0·67	..	0·18	0·65	..
	1950	0·23	1·22	0·43	0·24	1·20	0·30

In arable-farming districts where one-year leys are included in the rotation it is interesting to compare the use of fertilizers on these leys and on the other temporary grassland. Table 10 shows that in 1950 in

TABLE 10. *Comparison of the Manuring of One-year Leys and Leys of Longer Duration in 1950*

	Percentage of acreage receiving			*Average actual rates cwt./acre*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Vale of York:						
1 yr. leys . .	17	15	4	0·22	0·88	..
2–7 yr. leys . .	37	52	23	0·40	0·76	0·63
E. Shropshire:						
1 yr. leys . .	63	52	40	0·28	0·76	0·28
2–7 yr. leys . .	78	69	41	0·44	0·89	0·34

both E. Shropshire and the Vale of York rather more of the leys of longer duration received fertilizers and the average dressings were also heavier than those on one-year leys. In the Vale of York in particular most of the one-year leys received no fertilizer dressing.

There is not sufficient information available to give a proper comparison within districts of the manuring of grazed grassland and of grassland which is cut for hay, nor of clovery *versus* grass leys. However, on the average the differences between the use of fertilizers on hayed and on grazed permanent grass within a homogeneous district appear to be small. In areas where F.Y.M. is used on the grass, as for example in SE. Cheshire and Northumberland, it is naturally applied to the hayed land.

Summary

This paper presents the information available on changes which took place in farmers' use of fertilizers between 1944 and 1950. The data have been largely obtained from the results of surveys of fertilizer practice carried out in eight districts in England and Wales in 1944–5 and in 1950; and, since no recent survey information for eastern England was available, it refers mainly to England and Wales excluding the south and east.

Estimates are made of the proportions of total fertilizer supplies used on different crops, and the trends in the use of fertilizers on individual crops are examined. As far as the limited survey material allows, differences in the use of fertilizers in districts of different farming types are discussed. The times and methods of application of fertilizers to cereals in 1950 are examined, and attention is drawn to the possibilities of increasing production by the more general use of nitrogen on cereals, fodder roots, and grassland.

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THE DESTRUCTION OR INHIBITION OF ROOT-KNOT NEMATODES BY EXPOSURE TO AN ELECTROSTATIC FIELD

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THE possibility of utilizing electricity to control root-knot nematodes Meloidogyne spp. (*Goeldi*) *Chitwood*, was suggested to Stokes by the apparent 'shock' to certain small insects when exposed to an electrostatic field. Investigations were then carried out in the laboratory, workshop, and field.

An attempt was made first to find whether nematodes could be destroyed by exposing them to an electrostatic field of a strength possible to produce under field conditions, and then to find the best method of producing such an electrostatic field during ordinary cultivation.

Test procedure.—In greenhouse and seed-bed experiments a tobacco variety susceptible to nematode was grown, and the nematode larvae used in the laboratory experiments were extracted from affected roots by crushing the galls. The extracted material was examined to ensure that only Meloidogyne forms were used. In each instance a sufficient number of larvae for immediate use only was withdrawn into a piece of glass-tubing by oral suction, transferred to the medium and treated immediately. Recovery after treatment was effected similarly. Evidence of effect on the eelworms was obtained by: (*a*) the appearance under the microscope of larvae extracted from the treated soil, and (*b*) examination for the presence or absence of root-knot galls on tobacco plants growing in previously sterilized soil into which treated media had been mixed.

Preliminary experiments.—In the preliminary tests it became evident that electric fields produced by the application of high-frequency alternating currents caused less damage to larvae than fields energized by pulsating direct currents. It was further observed that the frequency of interruption of the electrostatic field appeared to have a direct relation to the destructive effect upon the nematode. For instance, 66 pulses per sec. produced no effect, 166 pulses per sec. appeared to destroy some nematodes, but a frequency of 250 pulses per sec. destroyed all the larvae. The lethal area was found to be mainly but not exclusively between the electrodes. A conoid, extending outwards from each electrode at an angle of 45° to a line drawn between the electrodes, curved back to enclose a 'death area' of which the longest axis, at right angles to a line drawn between the points of discharge, was slightly less than the distance between them.

Field experiments.—First field tests in January 1951 indicated that an average lethal depth in the soil of 24 in. over a track-width of 24 in.

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could be obtained without the use of excessive power. Experiments carried out on prepared seed-beds demonstrated that tobacco seed of a variety susceptible to nematode attack germinated well in both treated and untreated beds, but growth-differences appeared after four weeks and became more pronounced with the passage of time. In the control beds the plants became heavily infested, but those in the treated beds showed negligible infestation, the degree varying with the spacing of the electrodes during the electrical treatment of the beds.

Prototype mobile unit.—The mobile unit comprises a 0·5 kw. d.c., shunt-wound generator, a rotary switch, an induction coil, and two insulated steel-disk electrodes.

The generator is driven by a V-belt connected to the tractor power take-off, is mounted on a framework just behind the driver's seat, and gives an output of 45 volts, at a speed of 1,440 r.p.m.

The rotary switch in the form of a commutator and brush gear, is mounted on the shaft extension of the generator, and serves to interrupt the d.c. output to the primary winding of the induction coil. By altering the number of brushes in contact with the commutator, the frequency of interruption can be varied over a range of 150 to 700 per sec. Across the interrupter switch is connected a condenser bank, variable between 11·5 mfd. and 50·0 mfd. in five steps.

The primary winding of the induction coil consists of 145 turns of 14 S.W.G. D.C.C. copper, wound on a 2 in.-diameter fibre tube, with a core of cross-section 1·767 sq. in. and made up from annealed iron wire 0·035 in. in diameter. The secondary winding comprises approximately 260,000 turns of 39 S.W.G. enamel-insulated wire.

At present, the electrodes in use are two insulated steel disks that rotate in light contact with the soil.

As a safety precaution against undue insulation stresses, should one of the electrodes momentarily break contact with the soil, a 2-in. gap is constructed permanently across the electrodes.

Mobile treatment with tractor unit.—Numerous tests were carried out with the prototype unit mounted on a tractor travelling at 4 m.p.h. over sandveld soil with a moisture-content of 2·3 per cent. in one instance and 9·7 per cent. in another. For these tests the electrodes were spaced at 36-in. centres, and the power input to the induction coil was reduced to 380 watts at 500 interruptions per sec.

Immediately before traversing the test area, nematode larvae were introduced into the soil at predetermined distances, and one electrical treatment was given. With electrode-spacing in excess of 36 in. in dry soil, some nematodes survived, but when the soil was moist it was possible to increase the electrode spacing to 42 in. and still destroy all nematodes introduced. With an electrode-spacing of 36 in. it was possible to destroy nematodes to a depth of 24 in.

Electrical treatment, applied to growing plants, resulted in no permanent detrimental effects, and in all cases the treated plants continued to grow normally and matured at the same time as other plants that had not been subjected to electrical treatment.

Microscopic study of treated nematodes.—When examined under the

microscope a striking feature of a female nematode that had been subjected to electrical treatment was the apparent shrinkage of the egg-mass resulting in a clear area around the perimeter, with the eggs concentrated in the middle.

It was observed that when water containing root-knot nematodes in all stages of the life-cycle was treated, the fully gravid forms frequently burst and disintegrated, whilst larvae straightened out completely when death occurred.

A comparatively small voltage was required to kill the larvae, but this voltage had to be increased to affect those in other stages of the life-cycle.

There were indications that fertilized females near full maturity were the most difficult to destroy.

Summary.—Root-knot nematodes in dry soil, damp soil, and water were destroyed when subjected to a pulsating electrostatic field set up by a simple induction coil across suitably spaced electrodes.

A compact unit, described herein, requiring less than 1 h.p. as a prime mover, and driven from the power take-off of a tractor, destroyed nematodes in the soil to a depth of 24 in. over a track width of 36 in.

The equipment was capable of destroying nematodes when using a frequency of interruption of the electrostatic field of 200 to 700 per sec., thus ensuring negligible loss of efficiency with ordinary variations in tractor speed, the average of which is 4 m.p.h.

Little mechanical strain is placed on the electrodes, since it is only necessary for them to be in light contact with the soil, and no appreciable draught is added to the tractor.

Tobacco plants showed no detrimental effects when subjected to the electrical treatment necessary for the destruction of nematodes.

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FODDER-BEET FOR PIGS

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ENCOURAGING results on the use of fodder-beet for fattening pigs have been reported by Braude and Mitchell [1], and by Dunkin and Cooper [2]. The former found that pigs of approximately 60 lb. initial weight, fed on 2½ lb. meal containing 15 per cent. fishmeal and beet to appetite, took about 11 days longer than the controls to reach bacon weight. The latter, who used heavier pigs (125–30 lb. initial weight) and basic meal 3 lb. found that those fed on 20 per cent. fishmeal grew as fast as the controls, whereas those on the 10 per cent. fishmeal mixture took about 16 days longer.

The trials here reported were designed to determine whether beet-feeding could be started at the 60 lb. stage without reducing growth-rate, and to give further information on the optimum protein-content of a 3 lb. basic meal allowance. A small trial on the feeding value of tops was carried out.

Method and materials. The 1949–50 trial included the following treatments:

I. Control. All meal-feeding according to scale given in Table 1.

II. Early start, beet. From 60 lb. live-weight, 3 lb. meal (containing 15 per cent. fishmeal), plus beet to appetite.

III. Late start, beet. Beet introduced at 90 lb., and meal reduced to 3 lb. plus beet to appetite at approx. 125 lb. Meal mixture as for II.

In the 1950–1 trial, treatments I and II were similar to those of the previous year's, apart from very minor differences. The third treatment, however, whilst similar to treatment II in other respects, had the fishmeal in the basic mixture replaced by a mixture of vegetable proteins and 3 per cent. fish solubles.

In the first trial 5, and in the second trial 6, blocks of Large White weaners were selected, each block consisting of three litter mates matched as far as possible for sex, weight, and previous growth-rate. Members of each block were allocated at random to each of the three treatments.

The entire group of pigs on each occasion was run in an open bullock-yard with covered sleeping accommodation, and fed individually. The Hunsballe X beet used was cleaned, and sliced not more than 24 hours before feeding. The daily ration of meal and sliced beet for each pig was weighed out into individual buckets and was then divided by eye into two, and later three, approximately equal feeds. Water, at the rate of 2 pints to 1 lb. meal was added. Additional drinking-water was provided. The meal mixtures are given in Table 3, the control mixtures being the same as those used in the earlier trials [2].

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TABLE 1. *Feeding Scale (Control Group)*

Live-weight lb.	*Meal daily lb.*
60	3·0
80	4·0
100	5·0
120	5·5
140	6·0
160	6·5
180 and over	7·0

TABLE 2. *Chemical composition of Main Mixtures and Beet, 1950–1.*

	'48'	'B'	'C'	*Beet*
Moisture	13·54	13·68	15·00	80·50
Crude protein	13·24	18·44	16·82	1·45
Oil	2·41	2·32	2·93	0·12
Carbohydrates	59·73	53·73	52·27	15·84
Fibre	5·51	4·72	7·13	0·97
Ash	5·57	7·11	5·85	1·12
	100·0	100·0	100·0	100·0
NaCl	0·6	0·73	0·48	0·0
CaO	..	..	..	0·13
P_2O_5	..	..	..	0·06
K_2O	..	..	..	0·27
Insoluble ash (siliceous matter)	..	..	..	0·12

TABLE 3. *Meal Mixtures*

	1949–50 and 1950–1						*1949–50*			*1950–1*
Treatment	*I*			*II*			*III*			*III*
Live-weight range (lb.)	*60–90*	*90–110*	*110–*	*60–70*	*70–80*	*80–*	*60–100*	*100–15*	*115–*	*60–*
Mixture			'48'			'B'			'B'	'C'
Barley meal	60	62½	65	60	60	60	60	60	60	35
Wheat offals	30	30	30	30	27½	25	30	27½	25	27
White fishmeal	10	7½	5	10	12½	15	10	12½	15	..
Pea meal	..	..	..	..	..	..	..	..	..	10
Bean meal	..	..	..	..	..	..	..	..	..	10
Linseed cake m.	..	..	..	..	..	..	..	..	..	10
Groundnut, dec.	..	..	..	..	..	..	..	..	..	5
Fish solubles	..	..	..	..	..	..	..	..	..	3
Minerals*	2	2	2	2	2	2	2	2	2	2½†

1 fluid oz. cod-liver oil weekly to all pigs added direct to trough.
* 1½% ground limestone and ½% salt.
† 1% ground limestone, 1% steamed bone-flour, ½% salt.

TABLE 4. 1949/50 *Average Performance for Period I (9 weeks) Treatment*

	Treatment			*Significance*
	I	*II*	*III*	
	lb.	*lb.*	*lb.*	
Total gain	64·4	59·2	64·4	N.S.
Meal consumption	248·0	177·4	210·0	
Beet consumption	..	263·2	121·4	
Dry-matter intake	214·4	202·0	203·8	
lb. D.M./1 lb. gain	3·33	3·41	3·16	N.S.

TABLE 5. *Total Live-weight Gains (21 weeks)*

Blocks	Initial live-weight (lb.)			Final live-weight (lb.)			Total gain (lb.)			Significance
	I	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*	
1	66	62	65	265	238	238	199	176	173	
2	63	61	61	215	203	225	152	142	164	
3	56	58	53	235	227	230	179	169	177	
4	51	49	52	211	233	221	160	184	169	
5	61	60	65	245	198	230	184	138	165	
Mean	59·4	58·0	59·2	234·2	219·8	228·8	174·8	161·8	169·6	N.S.

TABLE 6. *Food Consumption and Economy of Gains (21 weeks)*

Blocks	Total meal			Total beet			Meal per 1 lb. gain			Beet per 1 lb. gain		
	I	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*
1	820	418	469	..	1,663	1,532	4·12	2·38	2·71	..	9·45	8·86
2	768	422	447	..	1,398	1,536	5·06	2·97	2·73	..	9·85	9·36
3	770	418	433	..	1,657	1,498	4·30	2·47	2·45	..	9·76	8·46
4	715	413	430	..	1,584	1,413	4·47	2·25	2·54	..	8·59	8·34
5	786	419	469	..	1,293	1,379	4·27	3·03	2·84	..	9·37	8·36
Mean	772	418	450	..	1,519	1,472	4·44	2·62	2·65	..	9·40	8·68

		I	*II*	*III*	*Significance*
Mean	D.M. total intake	662·6	645·7	662·2	N.S.
	lb. D.M./1 lb. gain	3·83	4·03	3·91	
	Meal replacement value of beet	..	5·2	4·8	

D.M. Meal—86·3%. D.M. Beet—18·6%.

Results

1. *1949/50 Trial*

The trial is considered in two periods, the first lasting until 120 lb. live-weight was attained. At this point the Late-start Beet Group had reached its minimum meal allowance of 3 lb., and the second period then corresponds with the beet treatments of earlier trials [2] except for the protein-content of the basic meal-mixtures. Feeding three times daily was adopted during the second period.

During the first period four out of the five Early-start Beet pigs grew more slowly than their litter mates on the other treatments, but this difference, amounting to 5·2 lb., was not statistically significant.

In the second half of the trial No. 2 of treatment II fell about 20 lb. behind, due to a severe chill, whilst No. 5 of the same treatment developed the incurable habit of turning round in its crate. Their reduced growth from this stage has appreciably affected both their total gains and the mean for the group.

Over the full 21 weeks of the trial the Early-start Beet Group gained 7·8 lb. less than the Late-start, and 13·0 lb. less than the controls. Owing to the considerable variations within treatments I and II there was, however, no significant difference.

2. *1950/1 Trial*

Treatment III gave a uniformly lower growth-rate than the other groups during the early stages, although food-intake was slightly greater than for Treatment II. For the first six weeks, up to 110 lb. live-weight, average gains favoured the controls, treatment II gaining 3·7 lb. less and treatment III 8·0 lb. less. The difference between the controls and treatment III was significant at the 1 per cent. point, using the missing plot technique for pig No. 4 treatment II, which through illness had to be withdrawn from the trial.

During the last 13 weeks there was a general improvement in growth, but three weeks before the trial ended No. 1 of treatment III, which had the best performance in this group up to this point, developed a severe chill and had to be removed. No. 2 of treatment II was ill in the 13th week and its beet allowance had to be suspended temporarily.

Using the missing plot method for No. 4 treatment II and No. 1 treatment III, from 110 lb. live-weight both beet groups gained slightly, though not significantly, more than the controls. Taking the trial as a whole, over 19 weeks, from 70–220 lb., pigs receiving treatment II gained 4·8 lb. more than the controls, and those under treatment III gained 5·9 lb. less, though differences were not significant.

Discussion of Results

Growth performance.—Chills, which were unusually prevalent, occurred chiefly among beet-pigs, probably in part due to the relatively unprotected feeding accommodation. The beet-groups were certainly at a disadvantage in having to remain in the draughty feed-crates for 3–4 hours daily in the worst winter weather, whereas the controls, with a more concentrated ration, were usually confined for only 10 minutes per feed. In the second trial coughing was a complicating factor in the early phases. Although symptomatic of a sub-acute pneumonia, this condition does not appear to have altered the trend of results, and in a further trial with similar treatment to I and II, in which no coughing or illness occurred, results were practically identical.

Both trials indicate that from 60 to 110–20 lb. beet-feeding slightly lowers growth-rate compared with all-meal feeding, though only in treatment III of the second trial was this significant. At least with the 15 per cent. fishmeal mixture this small difference is more than compensated by the greater convenience of starting beet-feeding when the meal allowance has reached the level at which it will be maintained for the remainder of the fattening period. The slightly lower protein-content of the treatment III meal-mixture may account for the poorer growth on this treatment in the early stages.

In the first trial the control group maintained its lead throughout, but bearing in mind the reasons for the poor total gains by Nos. 2 and 5 of treatment II, this was not appreciable. In the second trial the control group occupied an intermediate position with the animal-protein/beet-treatment showing a slight advantage. It is possible that the higher

TABLE 7. *1950–1 Average Performance for Period I (6 weeks)*

	Treatment			Significance
	I	*II*	*III*	
	lb.	*lb.*	*lb.*	
Total gain	39·0	35·3	31·0	I > III**
Meal consumption	156·8	117·0	114·8	
Beet consumption	..	181·0	192·0	
Dry-matter intake	135·7	137·0	136·0	
lb. D.M./1 lb. gain	5·50	3·92	4·43	I < III** II < III*

TABLE 8. *Total Live-weight Gains (19 weeks)*

	Initial live-weight (lb.)			*Final live-weight (lb.)*			*Total gain (lb.)*			*Signi-ficance*
Blocks	*I*	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*	
1	79	80	76†	226	240	221†	147	160	145†	
2	65	65	65	220	208	202	155	143	139	
3	66	64	65	203	213	203	137	149	138	
4	69	69†	68	216	222†	211	147	153†	143	
5	69	67	68	226	215	218	157	148	150	
6	70	70	70	216	235	209	146	165	139	
Mean	69·7	69·2	68·2	217·9	222·3	210·7	148·2	153·0	142·3	N.S.

TABLE 9. *Food Consumption and Economy of Gains (19 weeks)*

	Total meal			*Total beet*			*Meal per 1 lb. gain*			*Beet per 1 lb. gain*		
Blocks	*I*	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*	*I*	*II*	*III*
1	734	371	370†	..	1,746	1,721†	4·99	2·31	2·55†	..	10·91	11·86†
2	692	369	362	..	1,227	1,350	4·47	2·58	2·60	..	8·58	9·71
3	651	370	367	..	1,472	1,428	4·75	2·56	2·66	..	9·88	10·35
4	697	371†	367	..	1,527†	1,502	4·74	2·41†	2·57	..	10·00†	10·50
5	696	369	367	..	1,323	1,338	4·43	2·49	2·45	..	8·94	8·92
6	696	371	368	..	1,601	1,406	4·76	2·25	2·63	..	9·70	10·12
Mean	694	370·2	366·5	..	1,483	1,458	4·69	2·43	2·58	..	9·66	10·24

		I	*II*	*III*	*Significance*
Mean	D.M. total intake	600·6	616·9	604·5	
	lb. D.M./1 lb. gain	4·05	4·03	4·25	I < III* II < III**
	Meal-replacement value of beet	..	4·3	4·9	

D.M. Meal: I—86·5%; II—86%; III—85%
D.M. Beet: .. II—20·1%; III—20·1%

† Calculated by missing-plot technique.
* Significant at the 5% point; ** Significant at the 1% point; N.S. Not significant.

D.M. content of the beet in the latter case was largely responsible for this improved performance.

Food consumption and efficiency.—In the early phase of the first trial treatment II gave a lower D.M. intake and was also less efficient than the controls. The better growth and improved efficiency of the Late-start pigs on a similar D.M.-intake may be explained by the fact that only 11 per cent. D.M. was derived from beet compared with 25 per cent. for the Early-start group.

In the second trial, where the D.M.-content of the beet was 1·5 per cent. higher, the D.M.-consumption for all treatments during the first six weeks was practically identical, but the requirements per lb. gain differed considerably, the controls being more efficient than treatment III (significant at the 1 per cent. point).

The fact that treatment III pigs ate more beet than those in treatment II suggests that their inferior growth in the early stages was not due to the respiratory trouble but to a qualitative difference in the basic meal-mixtures. Contrary to normal, D.M.-efficiency for treatment III improved during the later stages of fattening.

Since in neither trial from 60–120 lb. did pigs on *ad lib.* beet succeed in consuming more D.M. than controls, bulk appears to have been a limiting factor to growth at this early stage. In the later stages, however, D.M.-intakes for beet-treatments slightly exceeded those for controls, except in treatment II of the first trial, where the mean is influenced by the abnormally low figure for No. 5. Both trials suggest that D.M. from a bulky food is utilized less efficiently than from a concentrate.

Meal economy.—Feeding beet from 60–70 lb. live-weight required 45 per cent. less meal than all-meal feeding, about 3 cwt. meal being replaced by 13¼ cwt. of beet. Based on requirements per lb. gain, meal-replacement values for beet varied from 4·3 to 5·2 lb.; which are in agreement with those obtained in earlier trials. In the first trial about 32 lb. of meal per pig was saved by starting beet at the earlier stage.

Protein-intake.—Estimates of protein-intake for the various treatments are given in Table 10. Figures for digestible crude protein given by Woodman [3] have been used for the concentrates. Although beet is known to contain only small quantities of protein, there is little information on its value for pigs, and two figures were adopted, 0·3 per cent. and 0·7 per cent. protein equivalent, as representing the limits within which its true value probably lies. The figures given are necessarily approximations but illustrate a number of points.

First, in spite of relatively high-protein basic mixtures, the protein intake for beet-pigs in no case exceeds that for controls. This is of special importance in the early phase, when beet pigs have difficulty in keeping up with the controls, and it is possible that protein deficiency is partly responsible. Secondly, in the later phases when there was little difference in growth-rate between treatments, the all-meal group received about 15 lb. (30 per cent.) more digestible crude protein than was necessary for optimum growth. This suggests that the practice of using the equivalent of a 10 per cent. fishmeal mixture up to 100 lb. live-weight and a 5 per cent. mixture thereafter is wasteful of protein

for all-meal feeding; which is in agreement with Woodman's conclusions on the minimum protein requirements of the bacon pig [4]. Thirdly, the figures for fishmeal-intake draw attention to the greatest problem in utilizing a root crop efficiently for pig-feeding, namely the appreciable increase in the amount of protein concentrate required to achieve a balanced ration. Beet contributed not more than 15 per cent. of the total protein-intake, and it will be noted that 13–15 lb. more fishmeal per pig was used on the beet treatments compared with the controls. When it is remembered that the controls were themselves receiving an excess, the heavy demands on protein-rich concentrates for supplementing beet compared with all-meal feeding will be appreciated.

TABLE 10. *Estimated Protein Intake*

	I	*II*			*III*		
	Meal alone lb.	*Meal alone lb.*	*+Beet at 0·3% lb.*	*+Beet at 0·7% lb.*	*Meal alone lb.*	*+Beet at 0·3% lb.*	*+Beet at 0·7% lb.*
1949–50							
Period I (9 wks.) .	33·0	27·8	28·6	29·6	30·3	30·7	31·2
,, II (12 wks.) .	62·4	39·3	43·2	48·1	39·3	43·4	48·8
Total . . .	95·4	67·1	71·7	77·7	69·6	74·1	80·0
1950–51							
Period I (6 wks.) .	21·2	19·2	19·7	20·4	18·9	19·4	20·3
,, II (13 wks.) .	64·0	41·4	45·4	50·5	41·4	45·2	50·3
Total . . .	85·2	60·6	65·1	70·9	60·3	64·6	70·5

Fishmeal consumption

	I	*II*	*III*
	lb.	*lb.*	*lb.*
1949–50 . . .	46·1	59·6	58·3
1950–1 . . .	40·2	55·6	..

Carcass quality.—Carcass measurements and inspection gave no indication of any consistent treatment effect. Back-fat samples were taken for Iodine-Number estimations from only three control and 9 beet-pigs in the first trial, but the beet-pigs were at least as good as the controls in firmness of fat. More detailed data for the second trial are presented in Table 11. Treatment II gave appreciably harder fat than the controls (0·1 per cent. significance), and they were also better than treatment III beet-pigs (1 per cent. significance). There was a slight difference in favour of treatment III compared with the controls. The difference between beet-groups is probably accounted for by the linseed-cake meal, which contains unsaturated oils, in treatment III's meal-mixture.

Feeding value of tops.—With a view to gaining some information on the feeding-value of tops for fattening pigs, a small group-feeding trial was carried out in the late autumn of 1950. The effect of feeding roots

alone was compared with feeding the whole plant, which included about 25 per cent. tops on a fresh-weight basis. The same 3 lb. basic meal-mixture was provided in both treatments.

TABLE 11. *Iodine Number of Back-fat 1950–1 Trial*

Block	*Treatment*			*Significance*
	I	*II*	*III*	
1	62·6	53·2	58·5†	..
2	64·8	54·1	59·2	II < I***
3	64·1	55·0	58·2	II < III**
4	59·9	53·5†	59·0	III < I*
5	64·0	57·3	63·3	..
6	63·0	59·9	61·2	..
Mean	63·1	55·5	59·9	..

† Calculated by missing-plot technique.
* Significant at the 5% point; ** Significant at the 1% point.

Ten pens of five pigs, each paired for initial weight, were allocated at random, five pens to each treatment. The roots were allowed to wilt for 3–4 days before feeding and were roughly chopped with a spade. The bulk foods were fed to appetite. The trial lasted from 4 to 6 weeks, the average initial weight varying from 58 to 75 lb.

Growth-rate was fair for the stage of growth covered, and considering that the meal-mixture contained only 10 per cent. fishmeal. Dung from pigs on both treatments was loose at times, but no serious scouring occurred. The results suggest that at least when the crop is mature the whole plant can be fed almost as satisfactorily as roots, alone, though due to the lower D.M. of the leaves a greater weight is required.

TABLE 12. *Average Live-weight Gains and Food Consumption*

	I. Roots alone	*II. Roots and tops*
Initial live-weight, lb.	63·1	62·8
Final live-weight, lb.	100·4	99·7
Gain, lb.	37·3	36·5
Daily gain, lb.	0·94	0·93
Meal consumed, lb.	111·3	111·1
Beet consumed, lb.	192·3	215·8

Conclusions

In conjunction with a 3 lb. meal allowance containing 15 per cent. fishmeal or its equivalent, high dry-matter beet fed to appetite saved about 45 per cent. of the meal normally required, and without extending the fattening period. There appeared to be a slight tendency in the early stages for beet-feeding to reduce growth-rate, but this was negligible when the overall fattening period is considered. It is suggested that the

bulkiness of the ration and the quantity and/or quality of the protein available were limiting factors to growth at this stage.

All beet varieties are subject to considerable variation in dry matter with season and district, and in certain cases the bulk factor may become critical. If a beet of medium dry matter is used, or alternatively, if a high-protein meal supplement is not available, the meal allowance must be increased to avoid a longer fattening period.

Considering the possible complicating factors, it would be unwise to assume from the second trial that fishmeal is superior to vegetable proteins and fish solubles; at least, from 120 lb. the latter proved satisfactory.

In view of the increasing importance of carcass quality, the continued absence of any adverse effects from heavy beet-feeding is encouraging.

The fact that the whole plant may be fed to stores almost as satisfactorily as the roots alone indicates that in limited quantities the tops can be a useful addition, especially for older stock.

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GRASSES AND FODDER RESOURCES IN THE BRITISH TROPICS

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SURVEYS of the state of world food-supplies clearly indicate the necessity for large-scale expansion of food production if the standard of living and nutrition of populations, especially throughout the tropics, are to be improved. For this to be achieved and maintained, systems of agriculture involving better use of land will have to be practised. Extensive programmes of work aimed at expansion of animal industry together with higher production of arable food-crops will have to be undertaken. Soil erosion must be inhibited and greater attention paid to the maintenance of fertility and physical condition of soils. Badly eroded and derelict lands will have to be brought into economic production.

Accumulated scientific and practical evidence has shown that full exploitation of the potentialities of grasses, legumes, and other fodder plants can provide cheap and good methods to attain this end. Great emphasis is now being placed on the part grassland and fodder resources must play in building and maintaining agricultural and economic stability throughout the British tropics, from the densely populated areas of the West Indies with its large peasant population to the arid and semi-arid areas of Africa with their nomadic pastoral tribesmen.

An agricultural economy in which the ancient systems of monocrop and shifting agriculture will give way to organized systems of mixed farming or alternate husbandry is the aim. In pastoral areas animal output will have to be considerably increased. Severely over-grazed and deteriorated pastures will have to be brought back to the highest possible level of productivity and organized systems of grazing management practised—communal and otherwise.

A wide range of environmental conditions in the tropics creates diverse and complex grassland problems. In a continental block such as Africa varying altitudes result in divergent climatic conditions. On islands such as the West Indian group there is an insular tropical climate which is further modified by altitude. Here within a single small island the average annual rainfall in wetter districts may be around 200 in., as compared with less than 35 in. in the same year in drier coastal localities. The ecological problems, although diverse, present certain fundamental similarities which can be listed under (A) rainfall and temperature, resulting in large seasonal variation in productivity of grassland; (B) paucity of suitable pasture legumes; and (C) the inherent low production of indigenous tropical breeds of live-stock, particularly cattle.

A. *Rainfall and temperature.*—Annual rainfall throughout the tropics ranges from over 200 in. in humid areas to under 10 in. in arid areas.

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Precipitation in most areas is seasonal and often extremely erratic. Marked periods of wet and dry weather occur. Dry conditions are experienced for more than six months annually in many areas.

High temperatures experienced in tropical countries result in a high rate of evaporation, accelerating transpiration, and therefore the demand for soil moisture which then becomes a limiting factor for plant-growth. High soil temperatures result in rapid decomposition of soil organic matter. Adequate supplies of organic matter in the soil are essential for maintaining good physical condition and fertility of tropical soils. These factors emphasize the necessity for adequate ground coverage and indicate the important place of grassland, fodder plants, fodder trees, and the grazing animal, in well-designed systems of agriculture in the tropics. Grass, apart from being the cheapest and most valuable source of food for live-stock, serves to conserve soil moisture and is most important as a builder of soil fertility.

Rainfall fluctuations result in big differences in seasonal production of grasses and fodder plants. Luxuriant growth occurs in wet seasons and little or none in dry periods. There are therefore periods of abundance of fodder and, in the absence of good management and utilization of fodder resources, long periods of scarcity. This fluctuation has resulted in severe overgrazing and deterioration of pastoral areas, especially in arid and semi-arid regions, reducing some areas almost to desert, as in Northern Nigeria, Central and East Africa, and elsewhere. The better and more palatable species of perennial grasses have been killed out and in some pastoral areas of arid Africa only annual grasses, fodder trees, and browse plants are now left. Severe wind erosion follows and there is a high degree of run-off with little downward penetration of water at the onset of rains. Scarcity of fodder gradually becomes more acute under such conditions. Reports from Tanganyika [1] have stated that over 200,000 cattle die annually of starvation during the dry season due to scarcity of fodder and lack of water. Shortage of food for cattle and other live-stock presents a major grassland problem in tropical countries.

B. *Pasture legumes*.—Leguminous plants are usually high in their crude-protein content expressed as a percentage of dry matter when compared with grasses. They are capable of building up the nitrogen-status of soils by bacterial activities, together with the high nitrogen content of the plants. Such beneficial features are almost or completely lacking in tropical grasslands owing to the low percentage and often a total absence of leguminous plants in pasture swards. However, several promising species have been identified and there are good prospects of establishing balanced grass/legume mixtures at least in potential mixed-farming areas.

Numerous leguminous fodder trees are to be found in the tropics. Such trees play an important part in live-stock production, especially during the dry season in arid and semi-arid areas. They can be of immense value both as shade trees for stock and for grass in a scattered tree and grassland complex and on account of their nutritional value to live-stock by way of pods, seeds, leaves, and sometimes even bark.

C. *Inherent low level of animal production.*—Tropical breeds of cattle (*Bos indicus*) are inherently slow growers and show poor production as compared with temperate-zone cattle (*Bos taurus*). Animal-breeding work now in progress in the British tropical countries aims at improvement in type and production of live-stock. Such improvement will directly result in an inherent capacity to produce more. The plane of nutrition of such animals will have to be raised to exploit their improved potentialities. The effect will be a greater demand for more and better quality feed. Attention will have to be directed to the nutritional requirements of tropical live-stock. This aspect needs more detailed study. Temperate-zone standards for stock of high potential production, demanding a general high plane of nutrition, might be misleading when applied to indigenous tropical live-stock and crossbreds adapted to different environmental conditions and demanding lower planes of nutrition for an inherent lower production.

Present State of Knowledge

A. *Grasses, Legumes, Herbs, and Trees*

A provisional classification into three major types of agricultural regions based on climatic factors is given below.

(1) Areas within the economic limits of mixed farming (annual rainfall 30 in. and above).

(2) Semi-arid regions that are natural pastoral areas (annual rainfall 10–35 in.).

(3) Arid and semi-desert pastoral regions (annual rainfall less than 10 in.).

1. *Potential Mixed Farming Areas*

Traditional systems of monocrop and shifting agriculture predominate in most of these regions. Population pressure is high in most cases. Soil erosion and continuous cropping have lowered the fertility of soils. A system of intensive farming with an integration of live-stock and arable crops is highly desirable in these areas for crop yields to be maintained at better levels. Grasses, legumes, and fodder plants must assume the pivotal role in the farming rotation as temporary leys alternating with periods of arable cropping. In the cropping programme a good grass sward gives a most effective cover, protecting soil from erosion. The best physical conditions of soils for absorbing torrential downpours are produced and, given the grazing animal, legumes, and inorganic fertilizers, the fertility of soil is improved.

High-yielding grasses, legumes, and fodder plants are required to maintain this system at high economic levels.

Grasses.—A survey of the grasses and fodder plants of the tropics shows that a wealth of high-yielding indigenous grasses exists and suitable legumes have been isolated. A large acreage of permanent grasslands is found in these areas. These grasslands are predominatingly low yielding and, in the West Indies, include such grasses as Andropogon spp.

Axonopus compressus, *Stenotaphrum secundatum*, *Paspalum notatum* and other Paspalum spp., *Digitaria sanquinalis*, low-yielding strains of *Cynodon dactylon*, and other inferior types. Annual production of such pastures rarely exceeds 2 tons of dry matter per acre [2, 3]. Carrying capacity is low compared with natural *Panicum maximum* pastures in the same areas, which yield annually 4 tons and upwards of dry matter per acre [2]. The low state of productivity of such permanent pastures does not permit adequate conservation as silage, hay, or *in situ* for utilization in dry weather.

A similar picture presents itself in Africa. Large areas of low-production grassland are to be found in the Highland Forest Belt, Highland Grassland and *Combretum/Hyparrhenia* zones of Kenya, Uganda, and other parts of East and West Africa [4, 5, 6].

Species of grasses of much higher production in various tropical countries are: *Pennisetum purpureum*, *Pennisetum clandestinum*, *Tripsacum laxum*, *Panicum purpurascens*, *Melinis minutiflora*, *Cynodon plectostacyum et al.*, *Chloris gayana*, *Paspalum scrobiculatum*, *Paspalum dilatatum*, *Eriochloa polystachya*, *Setaria sphacelata*, *Setaria splendida* [2, 4]. In marginal areas better yielding drought-resistant types such as *Bothriochloa insculpta*, *Cenchrus ciliaris*, *Choris gayana*, *Pennisetum stramineum*, *Brachiaria brizantha et al.* [4] have been isolated. Several varieties of fodder sorghum have been produced for use as good-quality fodder for dry-season utilization. *Pennisetum clandestinum* has given very good results in the Highland Forest Belt of Kenya [7], especially in the presence of the indigenous *Trifolium johnstonii* and *T. semipilosum*. However, owing to its rhizomatous habit *P. clandestinum* is extremely hard to 'plough out' in established leys in high-rainfall areas.

Pennisetum purpureum, *Tripsacum laxum*, *Panicum maximum*, *Setaria sphacelata*, *S. splendida*, and Sorghum spp. are erect tall-growing species generally referred to as 'soilage' grasses. *Panicum maximum* is, however, a most valuable pasture grass both in semi-arid and humid areas of the tropics, and occurs naturally in the tall-grass/low-tree ecological belt of tropical Africa [1]. In Jamaica *Pennisetum purpureum*, particularly the Napier strain, has persisted with good production under grazing conditions for the entire period of a 4-year grass ley. *Tripsacum laxum* has also been subjected to light grazing in the West Indies. Toxic effects on animals produced by Sorghum spp., due to the presence of a cyanogenetic glucoside, especially in the young stage of growth, have greatly reduced grazing. Seed-production potentiality of grasses is also of great importance for large-scale pasture renovation. Cost of establishment is greatly reduced by the use of fully viable seed. *Pennisetum purpureum* and *Tripsacum laxum* produce seeds which for all practical purposes are sterile. Propagation is therefore done vegetatively. Most of the other grass species produce seed of extremely low viability. *Chloris gayana*, *Melinis minutiflora*, *Cenchrus ciliaris*, *Pennisetum stramineum*, and *Bothriochloa insculpta* are reported as good seed-producers [4].

Legumes.—Some of the promising perennial pasture legumes isolated are: *Pueraria phaseoloides*, several Stylosanthes spp., *Centrosema pubescens*, Alysicarpus spp., *Clitorea ternatea*, Lespedeza spp., *Calopagonium*

muconoides, *Dolichos hosei*, and several Indigofera spp. *Indigofera endecaphylla* has been found to produce toxic effects in cattle in Hawaii, Jamaica, and elsewhere. It should therefore be used with caution. Some strains of *Medicago sativa* (alfalfa), such as the Peruvian types, have shown good promise in Jamaica.

Annual legumes which have been used for ensilage include: *Glycine max* (soya bean), *Vigna unguiculata* (cow pea), *Mucuna atterima* (velvet bean), *Dolichos lablab*, and *Cajanus cajan* (pigeon pea). Search for more suitable pasture legumes is now being intensified in order to produce good grass/legume leys for the better nutrition of stock and, equally important, to build up and maintain the fertility of soils for good grass and also for crop production.

2. *Semi-arid Pastoral Areas*

These areas consist usually of low-yielding pastures, e.g. the Andropogon spp. pastures of the West Indies and the *Themeda/Acacia* grassland of Africa. Grazing is carried out extensively in very large paddocks, in Africa seldom less than 1,000 acres and often many square miles in area [5]. Heavy seed-producing perennial grasses are important because establishment by reseeding has to be carried out without the plough or cultivation. *Cynodon plectostacyum et al.*, Brachiaria spp., and other drought-resistant high-yielding types show good promise in these areas. The major problem is to provide adequate fodder for dry-season consumption. At present the carrying capacity of ranches is around 20–50 acres per beast. Increased carrying capacity together with extended periods of good quality fodder has been achieved by closer subdivision of ranches [5]. Fodder trees, herbs, and browse plants play a valuable part in the fodder resources and proper nutrition of stock, and these are invaluable as an integral part of the 'pasture' complex of such areas.

3. *Desert Scrub and Areas of High Aridity*

Such areas found in Africa have a dense cover of bush with ground flora consisting of herbaceous plants, chiefly grasses which are productive only during the wet period of the year [4, 5]. Annual grasses are prominent. In several districts the perennial species have been depleted by severe overgrazing. The sowing of suitable perennial grasses has been suggested for renovating such pastures. It is essential that perennial grasses be reintroduced into these areas in order to extend the grazing by adequate control and by measures of deferred grazing.

Fodder trees and browse plants.—French [8] has commented on the important part leguminous and other trees and browse plants have played in the survival of animals during long periods of drought in Northern Gold Coast, Northern Nigeria, East Africa, and elsewhere. The value of the pods and seeds of *Pithecolobium saman*, the leaves of *Brosimum alicastrum* (bread-nut), and other trees as food for live-stock is well known by farmers in Jamaica. As good potential dry-weather fodder, the value of the edible browse trees cannot be overlooked, especially in arid and semi-arid zones. Such trees are numerous in African grass-

lands. Trees such as *Gliricidia maculata*, *Erythrina berteroana*, *Leucaena glauca*, Acacia spp., and *Albizzia Lebbek* could be extremely useful to good live-stock nutrition in ley-farming areas [9].

B. *Strains and Ecotypes*

Several strains and a range of ecotypes within a number of grass species have been isolated. Different strains of *Panicum maximum*, *Pennisetum purpureum*, *Chloris gayana*, and *Paspalum notatum* are now widely used. Wide distribution of a number of species and strains has also produced many ecotypes. In Kenya [10] ecotypes of *Melinis minutiflora* and *Pennisetum clandestinum* have been discovered. In East Africa [4] there exist several ecotypes of Cynodon spp., *Cenchrus ciliaris*, *Setaria sphacelata*, and other indigenous grasses. Strains have varied widely in their morphological and physiological characteristics resulting in a range of adaptability to different environmental conditions. Some strains are more drought-resistant than others, e.g. *Panicum maximum* strains, Silk Guinea (Jamaica), Regular Guinea (Puerto Rico) are more adapted to dry coastal regions than other types grown under humid conditions, e.g. Gramalote (Puerto Rico), St. Mary's Cow Grass (Jamaica). Napier strain of *Pennisetum purpureum* has been found more drought-resistant than most of the other known *P. purpureum* strains. Strains have also displayed trends of differential seasonal production under similar environmental conditions. The length of time taken to reach maturity varies, causing peak growth-periods at different times of the year. This factor can be used to good effect in levelling the annual production of fodder, thereby maintaining a more steady rate of animal production. Better facilities are offered for management aimed at conservation *in situ* for consumption in dry weather. Strains and ecotypes have also shown different potentialities as seed-producers [4, 11].

C. *Inorganic Fertilizers*

The use of inorganic fertilizers containing calcium, phosphorus, nitrogen, and potash for increasing production of grasslands has been well established in temperate countries. Lime and phosphates have played a major role in improving and maintaining the percentage of legumes, especially white clover, in pastures in Britain, New Zealand, and elsewhere.

Soils are not by nature endowed with inexhaustible supplies of plant-food that can be drawn upon indefinitely. Year after year harvested or grazed crops are removing nutrients, including also the trace elements. Animal products sold off farms as milk, meat, and other live-stock products must tend to remove fertility from the land. As a result many pastures which were once productive have become so impoverished that they are no longer able to support vigorous growth of forages. This factor is emphasized in the absence of the legume or of the grazing animal, as when soilage, ensilage, or haymaking are practised. To maintain high production over prolonged periods the grazing animal and fertilizers are necessities. Fertilizer trials conducted in Jamaica [12, 13] and elsewhere have shown clearly that production can be economically

increased and maintained by the use of inorganic fertilizers applied to high-yielding species and strains, especially where known deficiencies exist in soils. Yields of Napier grass and *Panicum maximum* have been raised 50 per cent. and more on different soil types by the use of complete dressings of fertilizers (N, P, K, CaO). Excellent responses were obtained from nitrogenous fertilizers. Increases were of a much lower order on low-growing pasture types such as *Stenotaphrum secundatum* (St. Augustine grass). This further emphasizes the importance of species and strains, which are better 'machines' to utilize inorganic fertilizers and effect higher economic output from grassland without depletion of soil fertility. The high degree of phosphate fixation by the 'Red Dirt' (*terra rossa*) soils of the tropics presents added problems. Suitable methods will have to be devised for best use of phosphate on these soils (e.g. animal licks or new methods of application). The grazing animal becomes an extremely important factor on these soils, since organophosphates are not fixed easily by such soils.

D. *Management and Utilization*

Grasses and other fodder plants constitute a self-contained feeding-stuff. Good management aimed at proper utilization of fodders is therefore an important aspect of animal production. Maximum leaf-growth is highly desirable in good grassland management. The nutritive value of grass is in its leaf. A good grass therefore is one that will produce the maximum amount of leaf over the longest possible period. The grasses that suit any particular environment are those which maintain vigorous production of leaf under those conditions. Bulk and nutritive value are essential and so also are persistency and palatability. An optimum balance of quality, quantity, and palatability should be the aim, together with persistency of the sward. The first improvements should therefore be directed towards the most efficient methods of utilizing available resources in terms of potentially available pasture types.

Methods of utilization.—(Grazing, soilage, ensilage, and haymaking.) Work conducted in Jamaica, East Africa, and elsewhere has shown that organized systems of rotational grazing by proper subdivision of existing pastures can greatly increase production. The first phase in management and utilization of pastures must be proper grazing units. Rotational grazing facilitates the use of grasses at their optimum growth of leaf. A flow of good-quality feed is maintained and adequate rest periods allow plants to recover and to build up root-reserves. This is a factor of much importance in the maintenance of persistency and therefore in the improvement of physical conditions in the soil.

Excessive stem-growth should be avoided. Experiments conducted in Jamaica [2] have shown that there is a general increase in dry-matter production with advancing maturity. This increase in dry matter is accompanied by a rapid decline in percentage crude protein in the dry matter. For example, with Napier grass there is a decline in crude protein from 12–14 per cent. at the leafy stage to 4 per cent. at the mature stemmy stage. *Panicum maximum* shows a decline from 11–12 per cent. at the most leafy stage to 4–6 per cent. at mature stage. It is

therefore essential that a good balance be maintained between bulk and nutritive value, especially in the absence of legumes.

There will always be excess growth during the flush growing-periods of the year. The most efficient system of utilization is to conserve this excess growth for use in the periods of low production. Where facilities do not permit such practices, excess of stemmy growth should be cut, when grazing is practised, after leafage has been removed. The mowing-machine is highly effective for this operation. In some countries where extensive grazing is practised, the burning of pastures is carried out annually to remove excess 'stubble' growth. 'Burning' is a controversial topic among grassland agronomists and farmers in the tropics. Roseveare [14] says: 'To burn or not to burn? Opinions vary from definite "Yes" to an emphatic "No" with a whole range of intermediate views which see burning as a necessary evil, but one to be avoided if at all possible, and in any case to be carefully controlled.' In Kenya, Edwards [4] suggests that this 'necessary evil' has been used to good effect in the management of pastures. By periodical light burning the dominance of *Themeda triandra* has replaced the useless coarse grass phase dominated by *Pennisetum schimperi* at high altitudes.

A flame-thrower has been found effective and is recommended for use in South America [14] and Australia [15], especially on *Panicum maximum* pastures. If burning is to be practised it must be done systematically with full use of present knowledge, avoiding damage to young growing shoots and crowns.

The next phase aimed at higher production would then be the introduction of higher-yielding strains and ecotypes of fodder plants that are adapted to the particular environment. Selection of species and strains should be directed towards obtaining an even flow of good-quality fodder for live-stock during the entire period of twelve months or as near to this as the local environment and herbage available will allow. In mixed-farming areas adequate conservation of silage and/or hay to supplement dry-weather feed is an essential. Haymaking is now done only on a limited scale. This is due in great part to the erratic nature of tropical rainfall and lack of proper methods of haymaking under the prevailing conditions. In the West Indies silage is made in the dairy-farming areas.

By means of drought-resistant strains, together with the knowledgeable use of inorganic fertilizers and properly designed systems of rotational grazing, fodder can be conserved *in situ* for consumption by the grazing animal. Quality of grass will be reduced but defects can be made up by using leguminous and other fodder trees. These are grown on the pasture subdivisions and as scattered trees in pastures. Phosphate-content of grass has been found to fall rapidly from the green to the 'browned-off' stage [16]. The feeding of phosphate licks during this period will help to offset any deficiency of phosphate in the herbage. Pods and seeds of trees also have a high phosphate-content.

In semi-arid and arid areas deferred grazing on certain areas, during the growing-period for dry weather use, has yielded good results with the perennial grasses. With nomadic pastoral peoples the sociological

factors present practical difficulties in the control of grazing, but this can be overcome by proper management conducted in collaboration with the tribal chiefs. Conservation of adequate fodder on the ground as hay and/or silage is essential for good animal production in such areas. A suitable cover of perennial grasses is necessary to control erosion, and to arrest the present trends towards land depletion and the 'near desert' condition.

Future Developments

Adequate knowledge on management, strains, and ecotypes is available to plan immediate programmes of work for the improvement of the pastures and increase of productivity. Further experiments are, however, needed to ascertain:

(*a*) Better systems of management and fodder utilization.

(*b*) Suitable methods of seed production and pasture establishment.

(*c*) Methods of incorporating grass/legume mixtures in temporary leys and permanent pastures.

(*d*) The true value of fodder trees and browse plants in grasslands especially in semi-arid and arid areas.

(*e*) The fertility building potentialities of grasses and grass/legume pastures.

(*f*) Factors relating to nutrition of live-stock in the tropics together with intensification of live-stock improvement.

For maintaining good crop and animal production, long-term research programmes involving fundamental work aimed at solving the present problems are absolutely of prime importance.

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INVESTIGATIONS ON POTATO DISEASES AND PRODUCTION OF DISEASE-FREE SEED-POTATOES IN INDIA

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THE Second World War resulted in an increased demand for potatoes coupled with the complete closing down of the previous large importations of foreign seed-potatoes. The result was that a large and an ever-increasing demand for seed-potatoes had to be met and in some cases entirely new sources of material had to be found. A regular flow of potatoes cannot be kept up without a constant source of seed-potatoes of high quality and some system of maintaining freedom from disease on a large scale. In view of this the Indian Council of Agricultural Research initiated investigations on diseases of potato, particularly the virus diseases that are mainly responsible for 'running out' of seed-stocks, with the ultimate object of establishing Seed-Potato Certification which alone could put the potato industry in India on a sound footing.

A scheme was therefore started in October 1941 at the Indian Agricultural Research Institute with the following objects:

A. To make observations on the incidence and, as far as possible, on the spread of virus and other diseases with a view to selecting localities where the diseases causing degeneration were either absent or their incidence was extremely low.

B. To produce, multiply, and distribute certified disease-free seed-potatoes of standard commercial varieties.

The results of investigations on potato diseases and the production of disease-free seed-potatoes conducted in the Division of Mycology and Plant Pathology, Indian Agricultural Research Institute and its Sub-station, during the period 1941 to 1949 are presented in this paper. Some of the results already published have also been included so as to provide a connected account.

Occurrence and Distribution of Potato Viruses in India

Virus diseases of potato are prevalent in India wherever the potato crop is grown. Observations in the hills and plains of northern India show that their incidence varies from locality to locality, but is extremely high in most areas. In certain fields 100 per cent. infection has been observed.

Hills.—In Kumaon Hills the incidence of virus diseases recorded from 1942 to 1946 varied from 5·7 to 93 per cent. In Chakrata Hills the

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incidence during the same period varied from 3·1 to 66 per cent. In Kangra Hills the incidence of virus diseases as recorded in April 1942, March 1943, and May 1943 was 11·68, 19·36, and 21·33 per cent. respectively. In Simla Hills, as a whole, the average incidence in May 1942 and May 1943 was 17·75 and 12·6 per cent. respectively, but during 1945 and 1946 it went up to 41·1 per cent. It was, however, observed that mild types of mosaic were invariably predominant throughout, and the total incidence of virus diseases was comparatively low at higher altitudes, such as at Kufri.

Plains.—(i) *Bihar.* In the first potato crop it was observed during 1942–3 that mild types of mosaic were very common at Patna, Arrah, Bihar-Sharif, Gaya, Hazaribagh, and Monghyr. A severe type of mosaic was predominant at Muzaffarpur and Motihari. Spread of virus diseases was recorded after the first inspection of potato crop in December 1942. The spread was mainly due to mild mosaic at Patna, Arrah, and Gaya; to leaf-roll and mild mosaic at Monghyr; to severe and mild mosaic at Muzaffarpur; and to severe mosaic alone at Motihari. During 1943–4 the incidence of mild mosaic was highest at all the places examined. Incidence of severe mosaic was observed to be comparatively high at Patna; it was 7·15, 16·6, and 40 per cent. in 1943–4, 1944–5, and 1945–6 respectively. In 1945–6 incidence of mild mosaic to the extent of from 42·5 to 75 per cent. was also recorded at Patna.

(ii) *Uttar Pradesh.* In the first potato crop during 1942–3 mild mosaic was found to be widespread all over the State. Incidence of severe mosaic was high at Jaunpur, Basti, Bahraich, Lakhimpur-Kheri, Pilibhit, Hardoi, Lucknow, Pratapgarh, and Mainpuri. The data obtained strongly indicated a rapid spread of virus diseases after the first examination during November 1942. Average incidence of virus diseases in 1944–5 varied from 53·4 to 72·6 per cent. in the first potato crop and 62·7 to 72·5 per cent. in the second crop. In both the crops, however, mild mosaic was most predominant. Highest incidence of virus diseases in the State was observed at Farrukhabad, an important seed-distributing Centre.

(iii) *Punjab.* Average incidence of virus diseases in the first crop in 1942 varied from 11·6 to 36·0 per cent. Mild mosaic was most predominant. During 1944–5 the average incidence in the first potato crop varied from 82 to 88 per cent. and in the second crop it was 65 per cent.

(iv) *Bengal.* During 1943–4 mild mosaic was most prevalent at all the places inspected. The incidence of a severe type of mosaic was comparatively higher at Burdwan, viz. 15·1 per cent. During the first examination of the crop in January 1945 mild mosaic was found to be predominant at Bogra and Rangpur, whereas at Burdwan 50·3 per cent. of potato plants were found affected by severe mosaic, but the average total incidence of virus diseases varied from 64·4 to 94·4 per cent.

Observations on disease incidence show the widespread occurrence of virus diseases in almost all the potato-growing areas in the hills and plains of northern India. It has been, however, observed that there are a few pockets of low-disease incidence, e.g. certain localities at higher altitudes, and at Bihar-Sharif in the plains. To begin with, such areas

were considered more appropriate for concentrating seed-certification work.

Viruses affecting commercial stocks of potatoes.—The most important virus diseases of potato of common occurrence in India are mosaic, leaf-roll, and various types of necroses, and the viruses associated with these diseases are Solanum virus 1, 2, 3, 6, and 14. In addition, the presence of Solanum virus 4, 8, and 9 has also been indicated in commercial stocks.

Solanum virus 1, commonly known as potato Virus X, has been isolated from a number of potato varieties including Phulwa, Gola, and Darjeeling Red Round. On the basis of their reactions on differential hosts the various cultures of Solanum virus 1 have been divided into four groups [1]. Solanum virus 2 has also been isolated from several varieties including Phulwa, Gola, Majestic, President, Up-to-date, &c. In the Phulwa variety the virus causes either a very mild mosaic accompanied by veinal necrosis or severe mosaic alone, whilst in other varieties it produces various forms of necrosis [2]. Pal [3] had also earlier recorded the infection of Solanum virus 2 in Phulwa variety. Solanum virus 3 was recovered from potato varieties Phulwa and Darjeeling Red Round; in the former it causes yellowing of the leaf-margins or deep yellow brilliant mottle, and in the latter the chief symptom is crinkling of the leaves [4]. Solanum virus 6 was also isolated from the Phulwa variety [5].

In addition to the viruses recorded above, natural infection of tobacco leaf-curl virus (Nicotiana virus 10) was observed in potato varieties Darjeeling Red Round, President, and Craig's Defiance [6].

Complex virus diseases caused by combination of two or more viruses are also of common occurrence, e.g. crinkle in Gola and rugose mosaic in Phulwa. It has further been found that Solanum virus 1 is of widespread occurrence, and all the commercial Indian varieties have been found to be invariably infected with one or other strain of the virus.

Experiments have shown that in India, as elsewhere, the yield from plants affected with different virus diseases is lower than that obtained from healthy plants. The reduction in yield, however, varies with the intensity of the disease, being obviously highest in severe types of infection. The data collected show that the reduction in yield brought about by severe virus diseases such as rugose mosaic and leaf-roll is as high as 72 to 92 per cent., and due to mild mosaic as much as 52 per cent. The economic loss due to mild mosaic on the whole is considerable because of its widespread occurrence [7]. It has also been observed that there is reduction in yield even when the plants carry virus infection without exhibiting any visible symptoms depending on the period of masking.

The total area under potatoes in India in 1950–1 was 588,000 acres, producing about 1,629,000 tons of potatoes. In view of the high incidence of virus diseases the loss in total food-supply of the country and national income is considerable. The imports of potatoes from foreign countries during 1948–9 were 328,000 cwt.; valued at Rs. 6,134,000. Such annual drain on the national income can appreciably be mitigated if disease-free seed-potatoes of desired quality are made available to the growers in sufficient quantity to increase production.

Seed Certification

As the virus diseases affecting the potato crop are tuber-perpetuated, the only practical method of combating them is the production of disease-free seed and its distribution to the growers in sufficient quantities. The purpose of Seed Certification is twofold, viz. varietal purity and freedom from disease. The work of Seed Potato Certification has to be accomplished in two stages: the first is the building up of a virus-free nucleus of standard potato varieties, and the second multiplication of the nucleus and its subsequent distribution to the growers under a recognized system of certification [8].

A. *Production of virus-free nucleus stock.*—Work in this connexion was first taken up with important Indian commercial varieties in 1943. Mass selection of apparently healthy plants of Phulwa, Darjeeling Red Round, and Gola varieties raised at Delhi and Karnal, from seed samples originally collected from Bihar, Darjeeling, Meerut, and Farrukhabad, was carried out. It was in the first instance made sure that the material selected was true to variety; and only the plants showing vigorous growth and promise of health were selected. Great care was taken to eliminate 'bolters' and 'wilding' types during the primary selection. A total of 4,312 apparently healthy plants was selected. Tubers from each of these plants were planted in 'hill units' at the Central Seed Potato Certification Station, Kufri, situated at an altitude of about 9,000 ft. in Simla Hills, in the summer of 1944 for further selection. The station at high altitude was selected because of low aphis incidence, unfavourable conditions for their movement for most of the potato-growing season, and masking of disease symptoms. The growing crop at Kufri was carefully examined for virus diseases three to four times at different stages of growth, and all the diseased plants, including those which showed doubtful symptoms, were rogued out. Tubers obtained from these selections were planted for further selection in 1945. As soon as any plant in a unit was found infected, the whole unit was discarded. By the process of elimination only the best plants were kept for further tests.

A few tubers from each of the plants thus selected at Kufri were 'indexed' and grown in an insect-proof house at Delhi. The plants were carefully observed for disease symptoms, and all the apparently healthy plants were tested on differential hosts such as *Nicotiana tabacum*, *Datura stramonium*, *Capsicum annuum*, and *Solanum nodiflorum*, in order to confirm their freedom from virus infection. These tests were repeated at least three times. Besides sap-inoculation, grafting to the differential hosts, including potato varieties President, Epicure, Up-to-date, and Arran Victory, was also carried out. In this way, in 1945, seventeen disease-free plants of variety Darjeeling Red Round were selected. In the case of Phulwa variety, some plants showing promise of health have been selected, but are still under test; but no healthy plants of Gola have so far been obtained. In 1946, in addition to the material of varieties Darjeeling Red Round, Phulwa, and Gola, apparently healthy selections of Up-to-date and three potato hybrids, 2, 9, and 12, evolved by the

Botany Division of this Institute, were also tested for freedom from virus infection in the insect-proof house.

Meanwhile multiplication of the virus-free material of Darjeeling Red Round, evolved in 1945, was undertaken in an isolated plot at the Central Seed Potato Certification Station, Kufri, whilst a small nucleus continued to be maintained in the insect-proof house at Delhi [9]. The multiplication of the virus-free nucleus of Up-to-Date, which is an important variety in the hills as well as in some areas in the plains, was also taken up at Kufri.

After having produced the virus-free material of Darjeeling Red Round and Up-to-Date, work on similar lines was started with some of the promising potato hybrids evolved by the Botany Division of this Institute. With this object in view during 1947 and 1948 apparently healthy selections were made from the following thirty-six hybrids, some of which may prove suitable as commercial types in certain areas:

(*a*) *Hybrid nos.* 2, 5, 8, 9, 10, 11, 12, 13, 16, 18, 19, 28, 30, 31, 33, and 34.

(*b*) *Originals nos.* 45, 209, 175, 364(*a*), 375, 546, 782, 969, 978, 1046, 1093, 1272, 1352(*b*), 1360, 1362, 1903, 1949, 1995(*a*), 2090, and 2236.

During examination in the field, as well as on test in the glass-house, some of the material of these hybrids has shown promise of health, and will thus provide the disease-free foundation stock.

Disease-free material of some important exotic varieties of potato was also multiplied on a small scale at Kufri, whilst the nucleus stock was continued to be maintained and kept under observation in the insect-proof house at Delhi. Some of these exotic varieties, viz. President, Craig's Defiance, USDA seedling 41956, &c., have commercial possibilities in India. In addition, disease-free nuclei of three clones of Up-to-date, viz. 5 × 950, F × 728, and F × 950, obtained from Australia, were also under trial.

B. *Certification.*—Having produced the virus-free nucleus stock the next step is to multiply it under conditions so as to maintain its freedom from disease. For seed-potatoes intended for the plains the material produced at the higher-altitude station has to be grown in mid-hills in order to make available non-dormant tubers for planting in the plains, because the harvesting season in higher hills and sowing-period in the plains almost coincide. In the plains the work of multiplication of the disease-free stocks has to be carried out by progressive growers under a recognized system of seed certification. In this way the degenerated seed stocks at present with the growers can be replaced by high yielding certified disease-free seed potatoes.

Partially Disease-free Seed-potatoes

Though the building up of a disease-free nucleus and its subsequent multiplication on a large scale and distribution to growers is the only practical method of combating virus diseases, it involves a long-range work which has to be carried out over several stages and will take a few years before disease-free certified seed is made available to the cultivators in sufficient quantities. Therefore, during the war, as an immediate

measure to step up potato production in the country, a scheme on the same principles as seed-potato certification but for the production of seed-potatoes free from only severe types of virus diseases such as severe mosaic, necrosis, and leaf-roll which could be made available to the cultivators without delay, was taken up during 1944 to 1947 [10]. In such partially disease-free seed stocks freedom from severe types of virus diseases is more or less achieved and this alone brings about substantial increase in yield per acre.

A. *Production and distribution.*—For the production of partially disease-free potatoes the commercial seed of Phulwa and Darjeeling Red Round varieties was purchased in 1944 from pockets of low disease incidence and planted at the Agricultural Sub-station of the Indian Agricultural Research Institute, Karnal. The crop was examined three times during the growing season and all the plants exhibiting symptoms of severe types of virus diseases were rogued out. The total percentage of plants thus rogued out varied from 21·0 to 27·0. In 1945 part of the material raised from the previous crop was planted at Karnal and also about 22 acres of standing potato crop with comparatively low disease incidence was purchased at Hapur in Uttar Pradesh. The total percentage of plants found infected with severe types of virus diseases in the crop at Karnal did not exceed 2–3 per cent. During 1946, in view of the very satisfactory results obtained from the crop purchased in 1945, the entire crop with low-disease incidence was purchased. During 1944, 1945, and 1946 altogether 963, 2782, and 3026 maunds (1 maund = $82\frac{2}{7}$ lb.) respectively of partially disease-free seed potatoes were produced and distributed to various States.

B. *Performance.*—The Department of Agriculture, Bihar, which took over a small quantity of seed-potatoes from the first lot in 1945, observed that the crop raised from the partly disease-free seed showed 3·5 per cent. disease incidence, as against 15 to 25 per cent. in the local crop.

The crop raised from seed material supplied to the Agricultural Department, Uttar Pradesh, gave considerably lower disease incidence than to the local crops. The yield was also considerably higher than that raised from the local crops. During 1947–8 a maximum yield of 427 maunds per acre was obtained at Hapur, and this has been considered by the Department of Agriculture, Uttar Pradesh, to be the record yield for Phulwa variety during that year. The disease incidence and out-turn of potatoes obtained from the crop raised from partly disease-free seed and from ordinary commercial seed are compared in the table on p. 299.

The data presented show that the performance of partly disease-free seed-potatoes has been extremely satisfactory from the point of view of disease incidence and out-turn. The germination was almost 100 per cent. in all the localities where the seed was grown. It was also observed that the crop raised from the partly disease-free seed-potatoes suffered less from the adverse effect of frost as compared with the local crop, and that the tubers were of better keeping-quality. The crop was also not so severely affected by the early blight which appeared in an epidemic form at Hapur in 1947–8. Until the certified disease-free seed is made

available to the cultivators in sufficient quantities, the partly disease-free seed-potatoes, which are already on large-scale multiplication and distribution in some of the main potato-growing areas, would rightly fill the gap, and will go a long way to step up potato production in the country.

Disease Incidence and Yield from Crop raised from Partly Disease-free Seed

Year	Locality	Partly disease-free seed		Commercial seed		Maximum yield (maunds per acre) from partly disease-free seed
		Disease incidence %	Average yield maunds per acre	Disease incidence %	Average yield maunds per acre	
1945–6	Meerut	3·5	233	20–25	175	300
	Farrukhabad	2–10*	235	60–70	200	322
1946–7	Hapur	3–4	250	20–70	175	..
	Farrukhabad	1–2	220	50–60	150–200	300
1947–8	Hapur	1–2	250	50–75	125	427
	Farrukhabad	..	250	..	..	..

* The higher disease incidence in Farrukhabad area was due to a heavily infected neighbouring crop.

Late Blight (Phytophthora infestans (*Mont.*) *de Bary*)

The disease is known to cause severe losses to potato crops, year after year, in the hills, as the conditions for the development of the disease there are favourable. In the plains, however, the disease was of rare occurrence and only a few cases of sporadic infection of late blight had been recorded in the past. In 1948 and again in 1949 the disease was observed in an epidemic form in Phulwa and Gola varieties in Hapur and Meerut areas in Uttar Pradesh [11]. Natural infection in the Phulwa variety, which is grown exclusively in the plains, was observed for the first time. The reappearance of the disease in 1949 in the same seed-stocks was due to the survival of causal fungus in the seed-tubers stored in cold stores during summer months. The potato cold stores are a recent introduction in India, and this explains why earlier the disease was of rare occurrence in the plains under ordinary storage conditions. In the plains the summer temperatures are high enough to kill the fungus.

Experiments with different fungicides with a view to control the disease were conducted at Kufri during 1948 and 1949. Spraying with Burgundy mixture (10:12½:50) and Perenox (¼ per cent.) was found to be quite effective against the disease, as it gave an increase in yield of 139·5 and 71·4 per cent. respectively over the unsprayed controls. Spray-with Dithane + $ZnSO_4$ + lime did not prove effective at Kufri on account of frequent high rainfall. The annual loss in yield due to the disease during 1948 and 1949 under the conditions of Simla Hills has been assessed at 58·2 per cent [12].

Transfer of Seed-potato Certification work to New Central Institute.— With the establishment of the Central Potato Research Institute at Patna during 1949, the sub-station at Kufri and entire work of Seed Potato

Certification, hitherto carried out in the Division of Mycology and Plant Pathology, was transferred to the new Institute along with all the potato material consisting of disease-free stocks of Darjeeling Red Round, which was already under large-scale multiplication and available in considerable quantities, and virus-free nucleus of other important varieties, e.g. Up-to-Date, President, Craig's Defiance, and many promising potato hybrids. It is for the new Institute now to take steps rapidly to multiply the virus-free nucleus for distribution to potato-growers under a recognized system of seed certification so as to replace the existing poor-quality commercial stocks of seed-potatoes.

Summary.—The occurrence and distribution of potato viruses in India and their importance from the commercial point of view are discussed. The work carried out in the Division of Mycology and Plant Pathology, Indian Agricultural Research Institute, regarding the production of disease-free seed-potatoes with the ultimate object of establishing Seed Potato Certification in India, is summarized. As a result of this work virus-free stocks of some important commercial varieties and potato hybrids have been evolved. As an immediate measure to step up potato production, partly disease-free seed-potatoes were produced in large quantities and made available to the growers. The performance of such seed was found to be very satisfactory both as regards disease incidence and out-turn.

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THE INFLUENCE OF CULTURAL AND MANURIAL FACTORS ON PLANT DEVELOPMENT AND YIELD OF THE POTATO

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Introduction.—In spite of much work done on the manuring of the potato crop in the British Isles [1–4], data are lacking on the modifying influence of cultural factors, such as planting-time, spacing, and seed-size, on the fertilizer response. There is also little information on the interrelation of cultural factors, and some of these, e.g. planting-date and spacing, have not received adequate attention, even singly.

The effect of seed-size has, however, been studied frequently [5–9], and has led to the generalized conclusion that the best seed is equal to the size of a hen's egg. Bates [10] reported the results of a two-factor, seed-size and spacing, experiment that was repeated over two further seasons [11]. These studies brought out the importance of the two factors on yield and the size of tubers, but the interaction was not significant. The minimum spacing tried in the above experiments was, however, 12 in. between the setts, and the range of seed-sizes covered was rather narrow (1 to 2·5 oz.) considering the present-day authorized specification ($1\frac{1}{4} \times 2\frac{1}{4}$ in.).

The need was therefore felt for a comprehensive study of the diverse factors on modern lines, and carefully-designed experiments were laid out at Edinburgh in 1946 and 1947. In 1946 attention was confined to the cultural factors alone, under a uniform system of manuring. Replicated observation plots without any fertilizer treatment served as a basis for the simultaneous study of the cultural and the nutritional factors in 1947. In both years, in addition to final yield, many observational data were collected for interpretation of the treatment effects.

The weather in the two years of the experiments differed widely. Briefly stated, 1946 had a bright early spring and extremely wet weather from mid-July to mid-September; 1947 will be remembered for a cold and wet spring (responsible for a general delay in planting) and exceptionally bright, dry, and hot weather during active tuberization in August. Late blight appeared in early September in the wet year. Data on the fortnightly rainfall (in mm.) in the two seasons are given below:

	Fortnight ending											
Year	*29/4*	*13/5*	*27/5*	*10/6*	*24/6*	*8/7*	*22/7*	*5/8*	*19/8*	*2/9*	*16/9*	*30/9*
1946	15·2	0·3	37·3	33·2	15·7	28·3	59·4	31·7	94·6	28·6	78·4	21·1
1947	71·2	33·6	15·4	48·2	40·1	16·0	68·4	19·8	1·3	..	20·7	21·5

Experiments in 1946

An area of about $2\frac{1}{2}$ acres in Anchordales field at the Boghall Experimental Farm, Edinburgh, was selected for one main experiment and

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three subsidiary experiments. The soil is a gravelly sandy loam of average fertility and of slightly acidic to neutral reaction. The previous crop was oats. The area received farmyard manure at 15 tons per acre in winter.

Main experiment.—The treatments were all combinations of the following factors:

Factors:	*Planting-date*	*Spacing*	*Seed-size*	*Time of lifting*
Levels:	d_1 = 10/4/46	27 × 8 in.	$s = 1\frac{1}{4} \times 1\frac{1}{2}$ in.	t_1 = 8–10/9/46 (haulms killed
	d_2 = 30/4/46	27 × 16 in.	$m = 1\frac{3}{4} \times 1\frac{7}{8}$ in.	
	d_3 = 20/5/46	27 × 24 in.	$l = 2\frac{1}{8} \times 2\frac{1}{4}$ in.	t_2 = 19–22/10/46

with fourfold replication. Planting-dates and spacings were assigned to the main plots; seed-sizes, to the semi-main plots, confounding triple-factor interactions partially; and lifting times, to the arrays. The statistical aspects of the designs have been discussed in a previous paper [12].

Before each planting, 10 cwt. per acre of compound potato fertilizer (6 : 9 : 12) was applied as basal dressing. Plantings were done with Gladstone stock seed kept in sprouting-trays from April onwards after grading. The three seed-sizes designated as *s*, *m*, and *l* weighed 1·1, 2·3, and 4·3 oz. per tuber respectively.

Data were collected on (i) sprout emergence, from the medium spacing plots, (ii) height of eight plants per sub-plot, thrice in the season, and their node number finally from one replicate, (iii) yields of 'ware' (over $2\frac{1}{4}$ in.), 'seed' ($1\frac{1}{4} \times 2\frac{1}{4}$ in.), and 'chats' (under $1\frac{1}{4}$ in.) from each sub-plot (1/220 acre).

Subsidiary experiments.—1. A simple experiment comprising three planting-dates with three replicates was carried out to study the effect of this factor on yield in the absence of basal fertilizer treatment.

2. Two sets of plots were planted early, on 11/4/46, for studies involving removal of plants by sampling.

(i) For study of early development, an experiment with 3 seed-sizes, carefully selected for uniformity, was conducted in the absence of fertilizer dressing. Six replicates were provided. Before planting, samples of mother tubers were retained and later 4–5 tubers with sprouts were removed from each plot on 28–30/5, 11–13/6, and 29/6 for determining sprout-number and dry weights after drying the samples at 95°–100° C. in an electric oven. Twenty gm. of fresh pulp of mother tubers was extracted with 95 per cent. alcohol and later utilized for sugar estimations.

(ii) For studies on later growth, tuber-number and size, an experiment with three spacings assigned to the main plots split for 3 seed-sizes was conducted. Three replicates were provided. The area received basal fertilizer manuring as in the main experiment; 4–5 plants per sub-plot were removed on 15–17/7, 29–31/7 and 29–31/8/46.

Results

Treatment effects on plant development and yield are given in Tables 1–7 with standard errors of the means (S.E.) and critical differences (C.D.) at the 5 per cent. level, wherever possible. Crop values given in Tables 3–6 were calculated at the prevailing rates in 1946, viz. 'ware',

112*s.* 8*d.*; 'seed' A, 157*s.*; 'chats' 40*s.* per ton. To allow for variable seed planted under different conditions, net seed (gross seed produced *minus* seed used at planting) entered into these calculations.

Seed-size.—Sprouts from large seed emerged about 5½ days earlier than those from small seed, medium seed occupying an intermediate position (Table 1). Moreover, sprout-number increased progressively, though not proportionately, with seed-size. Doubling the seed-size did not double the sprout-number. Individual sprouts from large seed had, therefore, more reserve material to draw upon than those from small seed. The same was true of available food supply as suggested by the concentration of sugars. That the available sugars were actually removed in quantities proportional to seed-size is seen from the rapid decline in dry matter of all seed-sizes.

TABLE 1. *The Effect of Seed-size on Plant Development and the Mother Tubers*

	68% stand in June	Sprout no. per tuber	Sugars % on	Mother tubers								Node no. on	Inter-nodal length
				Dry-matter content %				Height (cm.) on					
			29/5	15/4	29/5	12/6	29/6	6/7	27/6	26/8	26/8	(cm.)
s	14·3	3·2	0·99	23·3	18·2	10·9	4·8	17·2	45·6	69·0	20·0	3.64
m	11·4	5·0	1·01	24·2	18·8	13·9	6·7	24·9	50·3	67·0	18·5	3·70
l	8·7	7·1	0·97	25·1	18·7	14·1	7·7	29·9	52·3	64·4	18·0	3·72
S.E.(±)								0·31	0·44	0·93	0·31	0·06
C.D.								0·88	1·26	2·65	0·94	0·18

Early emergence, greater sprout density (causing shading), and better food-supply per sprout contributed to the taller stature of plants from progressively larger seed-sizes in the early stages. By the end of July the differences in height scaled down considerably. Finally, the heights were inversely related to seed-size. The same was true of node (= leaf) number signifying later maturity of plants from small seed.

The individual sprouts from small seed recovered in shoot dry-matter faster than in height (Table 2). This resulted from profuse axillary development, specially near ground-level, and increases in the size and number of leaves. Consequently, dry matter per hill showed less disparity with seed-size as the season advanced.

TABLE 2. *The Effect of Seed-size on Dry Matter (vegetative parts excluding tubers)*

	Dry wt. (gm.)/sprout			Dry wt.(gm.)/hill					
	29/5	12/6	29/6	29/5	12/6	29/6	16/7	30/7	30/8
s	0·10	0·42	2·7	0·35	1·39	8·6	35·8	58·4	69·9
m	0·15	0·50	2·6	0·76	2·56	12·8	44·7	58·9	69·2
l	0·18	0·54	2·3	1·33	4·14	16·3	52·0	69·8	80·8
S.E.(±)				0·07	0·14	0·68	1·4	3·8	4·9
C.D.				0·23	0·45	2·17	4·3	11·6	15·2

The ratio root-and-stolons/shoot appeared to decrease with seed-size (Table 3). Corresponding with the fewer sprouts and less available food per sprout, small seed had also fewer tubers. This apparently reduced the internal competition between the organs above and underground in the case of sprouts of small seed, and helped them to recoup in top-growth. The extra growth in turn raised the size of the tubers or 'ware' proportion in the produce, though not to the extent of covering the depression resulting from reduced tuber-number. The gross yield, therefore, remained in favour of progressively larger seed sizes. The net yield (gross *minus* seed planted) was maintained over the range of seed-sizes tried. The net seed (seed lifted *minus* seed planted) increased with seed-size to the extent of decrease in 'ware'. This left a small margin of profit in favour of large seed in seed-production districts.

TABLE 3. *The Effect of Seed-size on Underground Development and Crop Value*

	Root per shoot on 12/6	*Tuber no. per hill*	*Wt. per tuber (gm.)*	*Ware %*	*Yield of potatoes (tons per acre)*						*Crop value £ per acre*
					Gross	*Net*	*Ware*	*Seed*	*Net seed*	*Chats*	
s	50·3	10·1	96·3	44·1	13·0	12·4	5·81	7·12	6·55	0·07	84·3
m	52·4	15·4	70·9	35·7	13·8	12·6	4·92	8·73	7·52	0·11	87·0
l	61·0	17·8	61·7	30·7	14·7	12·5	4·50	10·02	7·89	0·14	87·6
S.E.(±)		0·70	2·6	0·8	0·13	..	..	..	0·09	..	0·8
C.D.		2·17	8·0	2·3	0·37	..	..	..	0·25	..	2·3

Spacing.—In the early stages, height decreased with an increase in the planting distance from 8 in. to 16 or 24 in., but dry matter increased as spacing widened, demonstrating the differential behaviour of light intensity on apical growth and plant scaffolding. As the season advanced, the widely spaced plants made up in height and produced more leaves. Similarly, they gained in dry matter individually to get level with the closely spaced ones, on an equal area basis.

TABLE 4. *The Effect of Spacing on Crop Performance*

	Tuber no.		*Wt. per tuber (gm.)*	*Ware %*	*Yield of potatoes (tons per acre)*						*Crop value £ per acre*
Space	*Per plant*	*Per sq. yd.*			*Gross*	*Net*	*Ware*	*Gross seed*	*Net seed*	*Chats*	
8 in.	13·3	80·0	53·4	20·9	14·8	12·6	3·15	11·4	9·31	0·18	91·1
16 in.	15·2	45·6	77·1	37·9	13·8	12·7	5·30	8·4	7·34	0·09	87·6
24 in.	14·6	29·3	98·4	51·8	12·9	12·2	6·78	6·0	5·32	0·06	80·1
S.E.(±)	0·37	..	..	0·85	0·23	..	..	..	0·12	..	1·4
C.D.	1·46	..	..	2·50	0·67	..	..	..	0·36	..	4·2

The number of tubers per plant increased but slightly to a point as spacing widened (Table 4), so that their number per unit area fell steeply as plant-population decreased. The widely spaced crop was thus handi-

capped but, as with small seed, compensation occurred through increase in tuber-size. The compensation was, however, inadequate, in that trebling the space only doubled the tuber-size. The gross yield per acre, therefore, fell off with plant density. Net yields showed smaller disparity with plant-number. The financial returns, however, remained in favour of thicker stands because of the preponderance of net 'seed' over 'ware'.

Seed-size and spacing.—The increase in seed-size or in plant-population independently raised the aggregate yield of potatoes, and their effects were largely additive (Table 5*a*). The nine treatment combinations fell into five yield-groups diagonally. Thus, the two factors were interchangeable. However, a unit change in spacing was more effective than that of seed-size.

TABLE 5. *The Interrelation of Seed-size and Spacing*

	Aggregate yield (tons per acre)						*(c) Crop value (£ per acre)*		
	(a) Gross			*(b) Net*					
	8 in.	*16 in.*	*24 in.*	*8 in.*	*16 in.*	*24 in.*	*8 in.*	*16 in.*	*24 in.*
s	14·0	12·9	12·2	*13·0*	12·4	11·9	*92·6*	83·5	76·8
m	14·9	13·4	13·0	*12·9*	12·4	12·3	*93·4*	86·3	81·3
l	15·4	15·1	13·5	12·0	*13·3*	12·3	87·3	*93·1*	82·3

S.E. Gross yield (seed-size comparisons) ±0·22 tons per acre.
S.E. Crop value (seed-size comparisons) ±1·41 £ per acre.

An allowance made for the variable seed requirements of the different combinations revealed that the use of large seed with close spacing was risky (Table 5*b*). Large seed spaced at 16 in., and the small or medium seed spaced at 8 in. gave almost identical net yields and were the most remunerative (Table 5*c*).

Planting-date.—A delay in planting of 20 days in April delayed sprout emergence by a week and that in May by about 9 days (Table 6). Thus, successively later plantings took less time in coming through the ground. They also grew faster and at the end of the season, curiously enough, height was inversely related to age. Late plantings made up in node number, had longer internodes, and exhibited more pronounced vegetative activity, which, however, was found to be at the expense of tuber

TABLE 6. *The Effect of Planting-date on Growth and Yield of Potatoes*

	68% stand in June	*Final ht. (cm.)*	*Internode*		*Yield (tons per acre)*				*Ware %*	*Crop value £ per acre*
			No.	*Length (cm.)*	*Total*	*Ware*	*Seed*	*Chats*		
d_1	4·0	60·4	18·8	3·47	15·2	6·87	8·22	0·11	45·8	93·2
d_2	10·6	67·7	18·8	3·52	14·2	4·74	9·33	0·12	34·1	90·0
d_3	19·7	72·4	18·9	4·07	12·0	3·62	8·31	0·10	30·7	75·6
S.E.(+)		1·55	0·38	0·15	0·23	..	..	..	0·85	1·4
C.D.		4·53	1·12	0·43	0·67	..	..	..	2·50	4·2

yields. The depression in yield was 1 cwt. per day of delay in April and about double as much in May.

The yield of 'ware', or its proportion to the total yield, decreased with advancing planting date but seed fraction was the highest under the central planting. Therefore, the latter was as remunerative as the first planting in the seed-producing area.

Planting-date and spacing.—Early plantings remained superior irrespective of the spacing adopted. They were, however, at their best with close spacing (Table 7*a*).

TABLE 7. *The Interrelation of Cultural Factors (Yield of Potatoes in tons per acre)*

(*a*) *Dates and spacing*				(*b*) *Dates and lifting-time*				(*c*) *Seed-size and lifting-time*			
	8 in.	*16 in.*	*24 in.*		t_1	t_2	t_2–t_1		t_1	t_2	t_2–t_1
d_1	16·5	15·3	13·9	d_1	14·9	15·6	0·7	*s*	12·4	13·6	1·2
d_2	15·0	14·4	13·2	d_2	13·7	14·7	1·0	*m*	13·4	14·2	0·8
d_3	12·9	11·7	11·6	d_3	11·7	12·4	0·7	*l*	14·4	14·9	0·5

Mean response to lifting time 0·81 ± 0·26 (significant at 1 per cent. level)

Lifting-time in relation to planting date and to seed-size.—Strangely enough, late plantings derived only as much benefit from delayed lifting as did the early one (Table 7*b*). The small seed, however, profited more than the large from delayed lifting (Table 7*c*).

Planting-time in relation to manuring.—The yields of the successive plantings in the absence of fertilizer treatment were 10·1, 11·5, and 10·1 ton per acre respectively. Thus there was no regular decline in yield here, contrary to the progressive diminution in yield with delay in planting in the presence of fertilizer dressing. This suggested that earlier plantings responded more to the fertilizer treatment.

Experiments in 1947

The 1946 results suggested that late planting, which tends to promote vegetative growth at the expense of storage, might not respond so well to nutrients which overstimulate vegetative growth (e.g. nitrogen) but might profit more from a plentiful supply of potash or dung. Nitrogen and potash treatments were, therefore, included with the cultural factors in the experiments conducted in 1947 in Hay Knowes field at Boghall, under similar conditions of soil, crop rotation, and basal dung-manuring as in 1946. The variety used was again Gladstone stock seed.

Main experiment.—The treatments were all combinations of

Factors:	*Planting-date*	*Spacing*	*Seed-size*	*Nitrogen*	*Potassium*
Symbols:	D	Sp	Ss	N*	K*
Levels:	$d_1 = 7/5/47$ $d_2 = 21/5/47$ $d_3 = 4/6/47$	27 × 8 in. 27 × 12 in. 27 × 16 in.	$s = 1\frac{1}{4} \times 1\frac{3}{8}$ in. $m = 1\frac{5}{8} \times 1\frac{3}{4}$ in. $l = 2 \times 2\frac{1}{4}$ in.	n_0 n_1 n_2	k_0 k_1

* n_0 and k_0 means no nitrogen or no potash; n_1 and n_2 consisted respectively of $2\frac{1}{2}$ and 5 cwt. per acre of ammonium sulphate; k_1 of 2 cwt. potassium chloride (60 per cent. K_2O).

in a single replication. There were three main blocks of nine main plots each for the allocation of combinations of planting-date, spacing, and seed-size. Main plots were split across for nitrogen, confounding some of the second-order interactions. The N plots were subdivided for the random distribution of potash levels. Fertilizer treatments were given according to plan in drills just before each planting. A basal dressing of superphosphate at 5 cwt. per acre was applied to all the plots. The plot-size measured $13\frac{1}{2} \times 24$ ft. at planting and 9×20 ft. for the record of final yield.

Observational plots.—Growth data were collected from a limited set of treatments comprising all combinations of

Planting-date	*Seed-size*	*Nitrogen**	*Potash**
d_1 = 8/5/47	s = 1 oz.	n_0	k_0
d_3 = 4–5/6/47	l = 4 oz.	n_2	k_1

* Treatments as above.

in two blocks of eight plots each. Seed-tubers were planted at 27×16 in. spacing. Each plot consisted of three drills, 164 ft. long, and only the central row was utilized for germination counts (whole row) and for periodic-growth data on five plant samples. The seed for the central row was specially selected for uniformity.

General observations.—Nitrogen-treated plots gave distinctly darker plants and potash-treated lighter than the corresponding controls. The potash also showed a bleaching effect on the tubers. Plots treated with both nitrogen and potash grew most vigorously. In August the plants from large seed and those treated with nitrogen showed wilting, which was less severe in the presence of potash. The latter induced characteristic upward curling of leaves (similar to leaf-roll) on plots of relatively heavy soil. The growth from late planting was softer and fresher than the early planting and with small seed and nitrogen treatment tended to produce long unproductive stolons.

Results

Treatment effects on plant development.—The main effects and the first-order interactions of the four factors under development studies are consolidated in Table 8.

As in 1946, the sprouts from small seed emerged later, were fewer in number and produced more nodes (= leaves) per stem than those from large seed. As against 1946, the small seed did not make up in internodal length, height, and the shoot dry-matter per hill. But in both years sprouts from small seed were stouter and more vigorous individually and developed fewer tubers (per hill) of larger size.

The influence of delayed planting on growth in 1947 (a dry year) was remarkably similar to that in the preceding wet year. Late planting covered part of the gap in emergence but even the diminished gap modified development profoundly. It induced the production of more sprouts and favoured extension growth as well as succulence. The late-planted crop, therefore, produced more dry-matter of the shoot than the early

TABLE 8. *Treatment Effects on Plant Development*

	Emergence date (June)	*Sprout no. per tuber*	*Height (cm.)*	*Node no.*	*Internode length (cm.)*	*Shoot dry matter*		*Tubers dry matter*			*Tuber no.*		*Wt. (gm.) per sizeable tuber*
						Gm. per hill	%	*Gm. per hill*		%			
								On 2–5/9	*Final*	*Final*	*Total*	*Size-able*	
Mean	20·7	6·50	55·4	20·1	3·22	58·4	9·14	136	181	25·2	18·9	9·3	73·1
Ss	−2·6†	5·41†	5·6†	−1·7†	0·62†	17·2†	−0·29	36†	36	0·7	7·8†	3·2*	−15·3*
D	16·2†	1·42†	9·2†	0·2	0·52†	8·6*	−1·22†	−35†	−13	−0·3	2·4	0·1	−9·3
N	−0·6	0·07	23·5†	2·0†	1·00†	36·8†	−0·60*	31†	63*	−0·1	2·1	1·2	19·5†
K	−0·3	−0·27	3·3*	−1·0*	0·33*	10·3*	−1·58†	11	8	−1·9†	0·4	1·1	−2·5
N.K.	−0·2	−0·15	9·7†	0·5	0·47†	10·2*	0·22	1	27	1·2*	−0·6	1·1	−2·8
D.N	0·1	0·10	−2·1	−0·2	−0·14	−7·8*	0·23	−23*	−13	−0·5	−0·6	0·3	−7·7
D.K.	1·2*	−0·26	3·3*	0·7	0·08	2·8	0·22	..	−10	0·7	−1·6	−0·4	−0·3
Ss.D	−0·8	0·97†	0·3	..	0·06	5·0	−0·03	11	−3	−0·2	−0·4	−1·2	9·7
Ss.N	−0·5	..	1·2	0·5	−0·02	−1·9	0·05	−7	−18	−0·1	−1·5	−1·2	−3·5
Ss.K	−0·8	−0·34	−0·3	..	−0·01	−2·0	−0·08	9	−7	..	−0·6	−1·1	6·4
Error (±)‡	0·3	0·20	0·9	0·3	0·08	2·4	0·14	5·7	14·5	0·33	0·9	1·0	3·6

* Significant at 5 per cent. level
† ,, at 1 per cent. level
‡ Based on second-order interactions (4 d.f.)

without a corresponding gain in tuber dry-matter. Late planting, however, tended to form more tubers consistent with more sprouts.

Nitrogen had little effect on sprout emergence or sprout number but influenced unmistakably all phases of growth. Nitrogen-treated plants produced more nodes (leaves) and had longer internodes correlated with succulence or reduced dry-matter in the shoot. They produced greater dry weights of shoots and tubers. The beneficial effect of nitrogen on tuber yield resulted from an increase in the size of tubers rather than in their number. Nitrogen application did not lower the final dry-matter percentage in the tubers.

The effect of the muriate of potash was not so marked as that of the nitrogenous fertilizer; it depressed the node number but increased the plant-height through the expansion of the internodes: an effect related to the increased water-content or reduced dry-matter content of the shoot. The potassic fertilizer increased the yield, but the increase was almost wholly made up of water, so that the effect on the dry weight of tubers was inappreciable.

The two factors, nitrogen and potassium, showed a strong positive interaction, i.e. they reinforced each other in the effect on growth. In fact, the main effect of potassium on height, internodal length, and dry matter derived significance from its positive pronounced effect only in the presence of nitrogen.

Nitrogen gave a smaller response with the later planting than with the early, signifying D × N interaction. The values for other interactions were in general small or negligible.

Growth analysis.—Net assimilation rates and leaf-weight ratios were calculated by methods developed by Gregory [13] and Briggs *et al.* [14]. The calculations were, however, based on weights and not on areas of leaf (Table 9).

TABLE 9. *Effects of Seed-size, Nitrogen, Potash, and Planting-date on Growth Analysis*

	Early planting				*Late planting*			
	26/6–10/7	*11–24/7*	*25/7–7/8*	*8–21/8*	*9–22/7*	*23/7–5/8*	*6–19/8*	*20/8–2/9*
				Leaf-weight ratio				
Ss	−0·107	−0·083	−0·048	−0·034	−0·020	−0·084	−0·030	−0·030
N	0·087	0·127	0·090	0·054	0·108	0·111	0·106	0·058
K	−0·009	−0·015	−0·028	−0·014	0·004	0·011	−0·019	0·001
Mean	0·325	0·373	0·280	0·187	0·319	0·407	0·302	0·200
				Net assimilation rate				
Ss	−0·20	−0·40	−0·35	−0·16	−0·58	−0·21	−1·00	0·01
N	0·44	−0·92	−0·25	−0·53	0·22	−0·13	−1·54	−1·04
K	0·14	−0·08	0·23	0·99	−0·06	−0·17	0·91	−0·48
Mean	2·68	2·31	1·93	2·66	2·33	2·26	2·98	1·48

The plants from small seed had a higher growth-rate because of consistently higher leaf-weight ratios and net assimilation rates. Late planting had higher leaf-weight ratios than the early at corresponding

stages of morphological development, and also a higher assimilation rate on corresponding dates. Nitrogen influenced the production of new material by maintaining higher leaf-weight ratios only, for its effect on assimilation rate, in the mid and the late season, was adverse owing to shading following profuse early growth. The potash showed a favourable effect on net assimilation rate during drought in August.

Treatment Effects on the Yield of Potatoes

Seed-size and spacing.—Gross yield in 1947 was not influenced by seed-size or spacing factor (Table 10). This result is at variance with that of the previous year, although the directions of effects on the yields of grades were the same in the two years. In 1946 large seed as well as close spacing caused sufficient increases in the seed to cover not only the depressions in 'ware' but also the extra seed planted. In 1947 these treatments increased the yields of seed and chats, only to the extent of reduction in 'ware', and the net yields revealed the risk involved in the choice of such treatments. It is noteworthy that a considerable fraction of the yield in the dry year, especially from large seed or close spacing, was made up of 'chats' which failed to develop into size on account of drought.

TABLE 10. *Effects of Seed-size and Spacing on the Yield of Potatoes (tons per acre)*

(*a*) Seed-size	Gross yield				Net yield	(*b*) Spacing	Gross yield				Net yield
	Total ±0·33	Ware	Seed	Chats			Total ±0·3	Ware	Seed	Chats	
s	10·1	3·83	6·05	0·25	9·6	*8 in.*	10·7	2·37	7·81	0·54	8·8
m	10·8	3·18	7·19	0·40	9·6	*12 in.*	10·1	2·98	6·76	0·38	8·9
l	10·6	2·44	7·60	0·54	8·3	*16 in.*	10·7	4·14	6·25	0·27	9·7

Grading analysis revealed that in the crop raised from small seed the yield of net seed increased progressively as spacing narrowed, and the increases covered largely the corresponding depressions in 'ware' (Table 11). Thus small seed could stand close spacing even in a dry year in seed-producing areas. As the seed was raised from small to medium and from medium to large, the favourable effect of close spacing on net seed produced gradually vanished, whilst the adverse effect on

TABLE 11. *The Interrelation of Seed-size and Spacing Yield of Grades (tons per acre)*

	Ware			Net seed			Chats		
	8 in.	*12 in.*	*16 in.*	*8 in.*	*12 in.*	*16 in.*	*8 in.*	*12 in.*	*16 in.*
s	3·07	3·38	5·05	6·19	5·42	4·78	0·34	0·24	0·17
m	1·95	3·57	4·07	6·44	5·83	5·78	0·57	0·37	0·27
l	2·04	2·00	3·27	5·15	5·24	5·39	0·72	0·54	0·38

'ware' persisted and a considerable part of the produce consisted of 'chats'. Large seed must, therefore, be spaced widely.

Planting-date, nitrogen, and potash.—Yield decreased by 1 cwt. per day of delay in planting and the decrease was shared by all grades almost equally (Table 12) (cf. 1946). A dressing of 2½ cwt. ammonium sulphate raised the yield by about 3 tons (33 per cent. over control). The double dressing proved a luxury dose. The positive effect of nitrogen on ware-proportion is in keeping with its effect on tuber-size. It is noteworthy that the response to nitrogen declined with advancing planting-date; in other words, in the absence of nitrogen, all plantings gave a similar performance, but in the presence of nitrogen early planting became superior.

TABLE 12. *Main Effects and Interactions of Planting-dates, Nitrogen, and Potassium on Yield (in tons per acre and percentage ware)*

	Dates and nitrogen			*Dates and potassium*		*Mean*	*% ware*
	n_0	n_1	n_2	k_0	k_1		
d_1	8·7	12·1	12·8	10·6	11·8	11·2	29·7
d_2	8·3	11·2	11·9	9·7	11·3	10·5	29·8
d_3	8·0	10·3	11·1	9·3	10·3	9·8	30·9
Mean	8·3	11·2	12·0	9·9	11·1		
% ware	21·4	30·3	38·6	28·1	32·2		

Nitrogen and potassium				*Mean responses (tons per acre)*	
	n_0	n_1	n_2		
k_0	8·0	10·7	11·0	D′ −1·41†±0·47	D″ 0·03±0·81
k_1	8·7	11·7	12·9	N′ 3·63†±0·20	N″ −2·16†±0·34
				D′.N′ −0·53*±0·24	D′.K −0·10±0·20
Apparent gain	0·7	1·0	1·9	K 1·22†±0·16	N′.K 0·53†±0·20
Real gain	0·2	0·2	1·1		

* Significant at 5 per cent. level. † Significant at 1 per cent. level.
Single dash = linear component; double dash = quadratic component.

The potassic fertilizer increased the yield significantly through an increase in 'ware'. The response did not vary with planting-date but was enhanced as the level of nitrogen rose. When allowance was made for increased water-content following potash applications, the response practically vanished at low levels of nitrogen but was still appreciable at the highest dressing of nitrogen.

Nitrogen in relation to seed-size and spacing.—The response to nitrogen diminished with increase in seed-size (Table 13*a*). Regarding spacing, 12 in. proved to be the most responsive (Table 13*b*). These results may, however, be modified if the water-supply is not limiting.

Spacing and planting-date.—The first planting gave the maximum yield when spaced closely (Table 13*c*). The second planting gave the same yield irrespective of the spacing adopted. The third planting showed a progressive decrease in yield with decrease in spacing.

TABLE 13. *Interactions of Cultural and Manurial Factors Yield (tons per acre)*

(*a*) *Nitrogen and seed-size*				(*b*) *Nitrogen and spacing*				(*c*) *Spacing and planting date*			
	s	*m*	*l*		*8 in.*	*12 in.*	*16 in.*		d_1	d_2	d_3
n_0	7·5	8·8	8·7	n_0	8·7	7·6	8·7	*8 in.*	12·4	10·5	9·3
n_1	11·1	11·2	11·3	n_1	11·3	11·0	11·4	*12 in.*	10·1	10·5	9·8
n_2	11·8	12·4	11·8	n_2	12·2	11·8	11·9	*16 in.*	11·2	10·5	10·3
n_2-n_0	4·2	3·6	3·1	n_2-n_0	3·5	4·2	3·2	*16 in.*–*8 in.*	−1·2	..	1·0
N′.Ss′ = −0·56*±0·243				N′.Sp″ = −0·28*±0·14				D′.Sp′ = 1·06±0·57			

Single dash = linear component; double dash = quadratic component.
* = significant (5 per cent. level).

Discussion

Whatever the plant habitat, the total growth is a function of the initial weight, time, and the relative rate of increase in dry matter [15]. It would, therefore, be normally expected that variations in growth would be effected by seed-size on account of differences in initial food-store, by date of planting or lifting through differences in growth period, and by other factors such as nutrient supply by affecting the rate of growth per unit of material per unit of time. Nevertheless, the plants starting with an initial disadvantage may compensate in growth or final yield, though not always adequately, as every compensatory mechanism involves a time lag, and the growing season is inextensible beyond a certain limit. Thus, it is seen that the potato plants from small seed start off poorly, because of fewer sprouts and a smaller weight per sprout, but that they tend to recover by producing proportionately more assimilating material and maintaining higher net assimilation rates, on account of the greater resources of light, water, and nutrients available per sprout. The recuperated top-growth raises the size of the tubers in the produce, though the compensation is inadequate to offset the influence of reduced tuber-number on yield. But any factor (e.g. drought in 1947) that limits the full expression of the potentialities of large seed apparently helps the small seed to come up and prove economically superior. The behaviour of spacing, which affects sprout density in proportion to spacing, could likewise be explained (see also Bates [10]). It is thus understandable that when large seed is spaced closely the internal competition is so severe that the returns are not commensurate with extra seed-costs, particularly in the dry year. Seed-size and spacing should, therefore, be properly balanced.

Late-planted potatoes grow faster and actually outstrip the early planted in height by elongating the internodes. Longer internodes are generally associated with larger leaf-size as well as better leaf-exposure and, therefore, improved assimilation rate. Consequently, late planting induces distinctly more vegetative activity which, however, is not reflected in tuber yields.

What stimulates late planting to pronounced vegetative activity? It can be inferred from its effect on the internodal length that a hormonal mechanism is involved. Successive plantings are exposed to different sets of environmental conditions, such as day-length and night temperatures, and these are probably the critical requirements for the storage phase. It may be recalled that, in the extreme case, late planting of small seed with nitrogenous manuring was observed to give unproductive long stolons: a behaviour akin to that of Solanum species when exposed to a day-length different from the one to which they are adapted [16]. Late sowings of mangold have also a similar vegetative tendency [17].

The late planting, on account of its tendency to grow vegetatively, appears to stand wider spacing better than the early [18]. This tendency also helps the former to get level with the latter in yield, if growth conditions such as nitrogen status, rainfall, &c., are restricted. Late plantings are, however, liable to be time-barred to develop into size the large number of tubers set under close spacing, or to return in yield the full advantages of added nitrogen. On the other hand, successive plantings have been found to respond equally to potassium chloride, in the dry year of 1947, although the suggestion that later plantings may profit more is not borne out. This point needs to be investigated further by including other sources of potassium in the experiments. Plants treated with potassium chloride showed distinct evidence of the effect of the chloride ion, in the form of longer internodes and a higher water-content of the shoot and the tubers. The presence of the chloride ion may have modified the influence of the potassium ion [4, 1].

The effects of seed-size and planting-date on plant development give the impression of an inverse relationship between growth and yield in the potato. Nitrogen, however, furthers growth as well as yield. This is because plants treated with nitrogen do not start off with any initial setback but gain in vegetative growth by virtue of high leaf-weight ratios, without any curtailment of the effective tuberization period. In fact, the roles of nitrogen on meristematic activity or extension growth are not only important for stimulating top-growth, but also ensure an adequate tuber-set and, more particularly, the enlargement of the cells of the tubers.

Summary

The investigation embodies the results of two comprehensive multifactor experiments and additional observation plots laid out at Boghall (Edinburgh) during the years 1946 and 1947, to study the optimal levels of the diverse factors and their optimal relationships in the potato (var. Gladstone).

1. The sprouts from small seed emerged later, were fewer in number, and had slower early development.
2. Tuber-number decreased with decrease in seed-size. Leaf-weight ratios and net assimilation rates remained higher in the plants from small seed. The resulting growth raised the tuber-size and the proportion of 'ware' in the produce.
3. In the wet year large seed out-yielded small seed to the extent

of extra weed-weight planted. In the dry year the small seed produced about as much gross yield as the large.

4. Close spacing acted like large seed on growth and yields. A unit change in spacing, however, produced more effect on yield characters than a unit change in seed-size.
5. Closer spacing of large seed was risky.
6. Deferred planting delayed emergence by one-third to one-half the interval between plantings and raised the sprout number slightly.
7. Late planting produced longer internodes, slightly higher leaf-weight ratio and greater succulence, but yielded less than the early planting.
8. The superiority of early planting was enhanced by close spacing and nitrogen application.
9. Nitrogen increased leaf-weight ratio consistently but depressed assimilation rate in the mid and the late season.
10. Nitrogen raised the tuber-size, the 'ware' proportion, and the yield.
11. Nitrogen acted best with early planting, small seed, and medium spacing (i.e. 12 in. between setts).
12. Potassium chloride increased extension growth, the water-content, and the assimilation rate (during drought), but not the leaf-number. It reinforced the effect of nitrogen on growth and yield.

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FODDER-BEET

PART II. A FURTHER COMPARISON OF DANISH FODDER-BEET AND ENGLISH MANGOLD IN THE SOUTH OF ENGLAND, 1950 AND 1951

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SINCE the original trials conducted by the authors [1], there have been numerous, and widespread, reports concerning the growing and the feeding of fodder-beet in Great Britain. Trials embracing the more important Danish, Dutch, and Swedish varieties have been reported from Essex [2], the west of Scotland [3], the east of Scotland [4], and Northern Ireland [5]. The National Institute of Agricultural Botany has also carried out variety trials at many centres, but as yet no results have been published [6]. Summarized details of several years' variety trials in Holland [7] are now available.

A general review of existing knowledge concerning fodder-beet based on experience in Norfolk and on information from abroad, has also been published recently [8]. The place of fodder-beet in Danish farm practice, and some typical dairy rations including fodder-beet, are described by Young [9], who states that in certain parts of Denmark fodder-beet almost takes the place of grass. Details of the cultivation and harvesting of fodder-beet as a commercial farm crop are given by Wilson [10] and Cullen [2], and a timely paper by Hull [11] concerning the disease Virus Yellows emphasizes the warning given previously [1] about this disease, and suggests methods of control. Owing to the interest centred around this crop a further two years' results concerning the relative output of nutrients from fodder-beet and mangold have been collected and are given in this paper.

Experimental Design and Methods

The field used for the trial in 1950 was of a heavy slow-draining loam in fair to good heart. In contrast, the field selected in 1951 was a light gravelly easy-working soil, free-draining, but of moderate fertility. From 15 to 20 tons of farmyard manure per acre were applied in winter to both the fields. In 1950 a dressing of 4 cwt. of superphosphate and 2 cwt. of muriate of potash per acre, and in 1951 of 3 cwt. of superphosphate per acre, were applied as seed-bed dressings. Seed was drilled on the flat in 25-in. rows at a rate of about 8 lb. per acre. Dates of drilling were May 16 in 1950, and April 25 in 1951.

The varieties of roots grown were: *English mangold*: Yellow Globe; *Danish mangold*: Barres Øtofte X; *Danish fodder-sugar-beet*: Red Øtofte X and Pajbjerg Red X.

The plot layout was similar to that employed in the two previous years and consisted of four randomized blocks each containing 8 sub-plots.

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Each of the four varieties was represented by 2 sub-plots in each block, one of which received a top-dressing of 6 cwt. per acre of sulphate of ammonia and the other no top-dressing. In both seasons the sub-plots were $1\frac{1}{2}$ chains long by 8 rows wide, although when harvested the outermost rows and 5 links at the end of each plot were discarded, leaving a plot of approximately $\frac{1}{40}$ acre.

The nitrogenous top-dressing was split each season, half being applied soon after singling and the other half when the plants were meeting in the rows. Dates of application were July 7 and 20 in 1950, and June 29 and July 17 in 1951.

The plant population of all four varieties was approximately the same at 23–25,000 per acre.

In 1950 the plots were harvested on November 2, 3, and 4, under particularly wet and sticky conditions, whereas in 1951 harvesting was completed in one day, October 29, when the land was fairly dry.

Sampling, estimation of dirt-tare, drying, and methods of analysis were identical with those reported in the previous paper [1].

Results

In both 1950 and 1951 over 13 in. of rain fell between the times of sowing and harvesting of the crop. July 1950 was a particularly wet month, having a total rainfall of 4·38 in.

TABLE 1. *Yield and Dirt-tare of Roots in 1950 and 1951*

*Nitrogenous top-dressing**	*Variety*	*1950*		*1951*	
		Yield of cleaned roots (tons/acre)	*Dirt-tare (%)*	*Yield of cleaned roots (tons/acre)*	*Dirt-tare (%)*
N+	Yellow Globe	38·71	10·7	23·71	8·5
	Barres Øtofte X	31·33	9·3	18·44	6·2
	Red Øtofte X	25·96	10·4	17·08	10·3
	Pajbjerg Rex X	20·95	25·4	16·17	13·8
N−	Yellow Globe	30·93	9·9	19·29	6·5
	Barres Øtofte X	23·22	9·4	18·83	5·1
	Red Øtofte X	20·91	12·0	14·95	9·4
	Pajbjerg Rex X	16·93	29·0	14·10	14·1
	S.E. per plot	2·11	2·2	2·38	2·2

* N+ indicates the application of 6 cwt. of sulphate of ammonia per acre.
N− indicates no application of sulphate of ammonia.

Details of the yield of cleaned roots and of the dirt-tare are given in Table 1. Yields in 1950 were, without exception, higher than those in 1951, the difference being most marked in the case of the Yellow Globe mangold. This difference may be attributable to the better land used in 1950 and to the heavier dressing of inorganic fertilizers. The trend in the yield of the different varieties was identical in both seasons either with or without the nitrogenous top-dressing. In 1950 differences

between the yield of individual varieties were all significant ($P<0.01$) but in 1951, although the Yellow Globe significantly ($P<0.01$) outyielded the Red Øtofte, there was no significant difference between the Pajbjerg Rex and the Red Øtofte.

With one exception the yield of roots was greater from plots that received the nitrogenous top-dressing. This effect was more evident in 1950 than in 1951, and was more marked on the Yellow Globe mangold than on the two varieties of fodder-beet, which showed no significant increase in yield as a result of this treatment.

As a result of the wet and sticky conditions of harvesting in 1950 the average dirt-tare of the Pajbjerg Rex beet was 27·2 per cent. This was more than double that of the other three varieties, which were not significantly different from each other. Even in 1951, under cleaner harvesting conditions, the Pajbjerg Rex beet had a significantly higher ($P<0.01$) dirt-tare than any of the other varieties. It is noteworthy that although both Red Øtofte and Pajbjerg Rex are classified in the same group of fodder sugar-beets [12], there is this large difference in dirt-tare percentage between them. The nitrogen application had a variable and non-significant effect on the dirt-tare.

TABLE 2. *Yield of Dry Matter per Acre and Percentage of Dry Matter of Roots*

Nitrogenous top-dressing	*Variety*	*1950*		*1951*	
		Dry matter in cleaned root (%)	*Weight of dry matter* (*tons/acre*)	*Dry matter in cleaned root* (%)	*Weight of dry matter* (*tons/acre*)
N+	Yellow Globe	10·1	3·89	11·1	2·63
	Barres Øtofte X	14·2	4·46	14·6	2·69
	Red Øtofte X	18·1	4·69	18·6	3·17
	Pajbjerg Rex X	21·2	4·42	18·7	3·02
N−	Yellow Globe	10·6	3·26	11·9	2·28
	Barres Øtofte X	15·6	3·60	15·3	2·90
	Red Øtofte X	19·0	3·98	19·0	2·84
	Pajbjerg Rex X	22·6	3·83	19·9	2·80
	S.E. per plot	0·7	0·27	0·5	0·34

The dry-matter content and the weight of dry matter per acre from the roots are given in Table 2. The values for dry matter follow a similar pattern in both seasons, and require little additional comment as the differences between the English mangold and the Danish beet are so marked. The superiority on the basis of dry-matter content of the Danish mangold (Barres Øtofte) over the English Yellow Globe is of note. The overall effect of the top-dressing was to lower significantly ($P<0.01$) the dry matter pereentage of the roots, this being more marked in the beets with the high dry matter.

In both 1950 and 1951 the Red Øtofte beet produced the largest weight of dry matter per acre although the difference between it and the Pajbjerg

TABLE 3. *Details of Yield and Dry-Matter Content of Tops of Mangolds and Beet in 1950 and 1951*

Nitrogenous top-dressing	*Variety*	*1950*			*1951*		
		Yield of fresh tops (tons/acre)	*Dry matter in fresh tops (%)*	*Weight of dry matter in tops (tons/acre)*	*Yield of fresh tops (tons/acre)*	*Dry matter in fresh tops (%)*	*Weight of dry matter in tops (tons/acre)*
N+	Yellow Globe	6·36	11·8	0·75	5·07	13·6	0·69
	Barres Øtofte X	11·79	10·6	1·25	6·23	12·3	0·77
	Red Øtofte X	13·59	10·8	1·47	8·59	12·2	1·05
	Pajbjerg Rex X	15·71	10·2	1·60	9·82	12·6	1·24
N−	Yellow Globe	3·14	11·6	0·36	2·89	14·6	0·42
	Barres Øtofte X	5·42	10·7	0·58	5·11	13·3	0·68
	Red Øtofte X	5·89	11·5	0·68	5·52	13·3	0·73
	Pajbjerg Rex X	6·36	11·4	0·73	7·29	13·7	1·00
	S.E. per plot	0·88	..	..	1·09	..	..

Rex variety was not significant. All the three Danish roots, including the Danish mangold, significantly ($P < 0.01$) outyielded the Yellow Globe in 1950, but in 1951 the difference between the Barres Otofte and the Yellow Globe was not significant. The Red Otofte significantly ($P < 0.01$) outyielded the Yellow Globe in 1951.

The top-dressing of nitrogen increased the output of dry matter per acre, with only one exception; this was the Barres Otofte in 1951. The overall effect of the top-dressing was highly significant ($P < 0.01$) in 1950, but non-significant in 1951.

As in previous years [1] the weight of fresh tops from each plot was recorded separately, but samples for drying and analysis were bulked from the four replicates. Thus, in Table 3 only a section of the results could be analysed statistically. In this table the difference in yield between the varieties is of particular interest; the higher dry-matter beets invariably producing twice, and sometimes nearly three times, as much weight of top as the mangolds. The effect of the nitrogen in increasing the yield of top was highly significant ($P < 0.01$) for each variety in 1950 and for the Pajbjerg and Red Otofte in 1951. The largest increase as a result of the nitrogen, 9·35 tons/acre, was on the Pajbjerg Rex beet in 1951.

In general there was little difference between the dry-matter contents of the tops of the varieties, the nitrogenous-dressing lowering the dry matter by about 1 per cent.

Details of the chemical composition of the roots and tops, including the percentage of sugar in the fresh roots, are given in Table 4. These results substantiate the analyses presented in the authors' previous paper [1] and indicate the differences likely to be found between the mangold and fodder-beet. The inclusion of the Barres Otofte in the trial forms an interesting and informative link between the composition of the low dry-matter English mangold and the high dry-matter Danish fodder-beet.

In both 1950 and 1951 there was a positive correlation between the dry-matter content of the root and the percentage of soluble carbohydrates in the root dry matter. On average there was about 10 per cent. more soluble carbohydrates in the dry matter of the beet than in the mangold, with concomitant decreases in the proportion of crude protein, fibre, ash, and ether-extract. The sugar-content of the fresh fodder-beet roots was generally double that of the mangold, and the Pajbjerg Rex variety averaged 14·0 per cent. in the two years. The ratio of true to crude protein was always higher in the fodder-beets than in the mangold.

The effect of the top-dressing on the chemical composition of all the varieties of roots was to increase both the true and crude protein of their dry matters with corresponding decreases in their soluble carbohydrate.

The crude-protein contents of the tops of the nitrogen-dressed beet and mangolds were again high, and in 1951 the tops of the Pajbjerg Rex which had been top-dressed contained 19·9 per cent. crude protein in their dry matter.

Although the beet crop is not normally considered a producer of protein, an output of over 8 cwt. of crude protein per acre was recorded

TABLE 4. *Chemical Composition of Roots and Tops in 1950 and 1951*

Nitrogenous top-dressing	*Variety*	*Percentage of dry matter of roots**						*True as % of crude protein in root dry matter*	*Sugar in fresh root (%)*	*Crude protein in dry matter of tops (%)*
		Crude protein	*True protein*	*Ether-extract*	*Soluble carbo-hydrates*	*Fibre*	*Ash*			
					1950					
N+	Yellow Globe	11·8	4·8	0·4	69·9	6·1	11·8	40·7	6·17	17·7
	Barres Otofte X	9·0	4·1	0·3	77·7	5·3	7·7	45·6	9·21	15·8
	Red Otofte X	8·1	3·9	0·3	80·9	4·5	6·2	48·2	11·63	14·5
	Pajbjerg Rex X	7·2	3·7	0·3	81·0	4·6	6·9	51·4	14·86	15·6
N−	Yellow Globe	6·2	3·6	0·3	76·4	5·5	11·6	58·1	5·98	12·9
	Barres Otofte X	5·1	3·2	0·3	81·9	5·2	7·5	62·7	9·97	13·3
	Red Otofte X	4·4	2·8	0·2	84·7	4·6	6·1	63·7	11·16	12·8
	Pajbjerg Rex X	4·3	2·9	0·2	84·7	4·6	6·2	67·5	15·86	13·0
					1951					
N+	Yellow Globe	13·4	5·6	0·4	68·4	6·2	11·6	41·8	6·13	20·1
	Barres Otofte X	9·7	4·2	0·3	76·4	5·7	7·9	43·3	9·70	20·2
	Red Otofte X	8·9	4·2	0·3	79·1	4·7	7·0	47·2	11·90	19·5
	Pajbjerg Rex X	8·6	4·0	0·3	78·6	5·0	7·5	46·5	12·20	19·9
N−	Yellow Globe	7·6	3·7	0·4	76·1	5·5	10·4	48·7	7·17	15·2
	Barres Otofte X	7·8	3·7	0·3	79·0	5·5	7·4	47·5	10·20	17·9
	Red Otofte X	6·2	3·6	0·3	82·7	4·7	6·1	58·1	13·25	14·3
	Pajbjerg Rex X	6·1	3·3	0·3	80·9	4·8	7·9	54·1	13·01	15·1

* The corresponding dry-matter contents of the fresh roots are given in Table 2.

from the tops and roots of the Pajbjerg Rex in both 1950 and 1951. The mangolds produced only slightly less protein than the beet, but its distribution as between root and top was different.

Discussion

The results given above and those published previously [1] can be usefully summarized to make a sound comparison between a typical variety of English mangold, the Yellow Globe, and a Danish fodder-beet, Pajbjerg Rex.

Excluding the results of the 1947 trial when the plots were not replicated, data from the four seasons 1948–51 inclusive were generally consistent and showed similar trends each year. The output of dry matter from the mangold and the fodder-beet when grown under identical conditions is given in Table 5. The seed of the Yellow Globe mangold was obtained from the same source each year and the Pajbjerg Rex beet was classified as strain IX in 1948 and 1949 and strain X in 1950 and 1951.

TABLE 5. *Yield of Total Dry Matter per Acre—Average of Four Years, 1948–1951 inclusive*

(Mean of N + and N − treatments)

	Weight of dry matter (tons/acre)		
	Cleaned roots	*Tops*	*Total*
Yellow Globe	2·90	0·51	3·41
Pajbjerg Rex	3·49	1·05	4·54

It will be seen that the fodder-beet produced 0·59 tons/acre more dry matter than the Yellow Globe from the root, and an extra 0·54 tons/acre from the tops. Calculated on the basis of the total output of dry matter per acre, the fodder-beet outyielded the mangold by 33 per cent. Even if the yield of the edible tops is excluded, the advantage still lies with the fodder-beet to the extent of 20 per cent. An average production of 1 ton of dry matter, including almost 4 cwt. of crude protein per acre from the tops of the fodder-beet is of interest, and emphasizes the need to make the fullest use of the beet tops if the maximum benefit is to be gained from this crop. These values based on four years' results are concerned only with a small number of varieties, but subject to this limitation there is every indication that the fodder-beet can produce a large weight of dry matter per acre and outyield a well-tried and popular variety of English mangold.

The average dry-matter content of the Globe mangold over the four years was 10·8 per cent. and that of the fodder-beet Pajbjerg Rex 19·6 per cent. Thus, not only did the fodder-beet outyield the mangold in terms of dry matter per acre, but this was produced consistently in a much more concentrated form.

On average, the effect of the nitrogenous top-dressing was to increase the output of both root and top dry matter and to depress the dry-matter

content of the roots and tops. The increases due to the extra 6 cwt. of sulphate of ammonia per acre were 8·5 cwt. and 4·5 cwt. of dry matter per acre respectively from the roots and tops of the mangold, and 3·5 cwt. and 7·5 cwt. from those of the fodder-beet. This differential response to the nitrogenous top-dressing indicates the need for a careful study of the manurial requirements of beet compared with that of the mangold. Unless a large quantity of leaf were required it would not seem as advantageous to apply a heavy nitrogenous top-dressing to the fodder-beet as to the mangolds. In fact, from these observations it would seem that for maximum production from fodder-beet a manurial programme similar to that for sugar-beet, in which the nitrogenous fertilizers are applied to the seed-bed, would be the best.

The dry-matter content of the fodder-beet was depressed by an average of 0·7 per cent. as a result of the top-dressings. Although this is not a large amount, any depression is to be avoided if the maximum use is to be made of the crop by pigs.

The large difference between the dirt-tare of varieties which had similar dry-matter contents and which produced almost the same weight of dry matter per acre (e.g. Red Otofte and Pajbjerg Rex in 1951) emphasizes the great care required in breeding and selecting varieties which have low dirt-tares even under sticky conditions of harvesting. The variety Red Otofte has proved particularly valuable because of its low dirt-tare and its ease of lifting.

Based upon the chemical analyses of the Pajbjerg Rex beet, and using the digestibility coefficients given by Woodman [13] for sugar-beet, the following feeding-value is suggested for fodder-beet with a dry-matter content of 21 per cent.: starch equivalent 13·0, protein equivalent 0·7.

Although realizing that each individual sample of beet can vary in composition and digestibility, it is thought that the above values are of sufficient accuracy for most feeding purposes. These figures emphasize the fact that fodder-beet is essentially a carbohydrate feeding-stuff with a wide nutritive ratio.

Although the exact place of the fodder-beet in dairy rations in Great Britain has not been fully ascertained, either from the economic or the nutritive point of view, results of pig-feeding trials continue to be encouraging. Trials in Scotland [4] have confirmed the value of beet as a meal saver, but stress the fact that a fodder-beet of high dry matter must be used for best results. Feeding trials with dairy cattle have been conducted at this Institute and the results will be communicated in a separate paper.

An average crop of fodder-beet can produce three, four, and even five times as much starch equivalent per acre as a normal crop of oats and, equally important, this can be done in areas of high rainfall where the risks of harvesting an oat crop are very great. Indeed, the greatest value of fodder-beet would seem to be in its wider use on the small farm where intensive production is the aim.

The fodder-beet offers many advantages when compared with the mangold, and although there is still very much to be learnt about this

crop under British conditions, there is every reason for encouraging its production at the present time.

Summary

1. Details are given of field trials carried out in 1950 and 1951 comparing two varieties of Danish fodder-beet, and one variety of Danish mangold with English Yellow Globe mangold, each at two levels of nitrogenous manuring.

2. The average yields in tons/acre of the cleaned roots were: Pajbjerg Rex X, 18·9 and 15·1; Red Øtofte X, 23·4 and 16·0; Barres Øtofte X, 27·3 and 18·6; and Yellow Globe, 34·8 and 21·5, in 1950 and 1951 respectively.

3. The average percentage of dry matter in the roots was Pajbjerg Rex X, 20·6; Red Øtofte X, 18·7; Barres Øtofte X, 14·9; and Yellow Globe, 10·9 per cent.

4. The results from the 1950 and 1951 trials agree in general with those of 1948 and 1949, and over the four years the fodder-beet Pajbjerg Rex has produced 3·49 tons of root dry-matter per acre and the mangold Yellow Globe 2·90 tons.

5. The conventional feeding-stuffs analysis and sugar contents of the roots are given. The dry matter of the beet had a higher soluble carbohydrate-content and lower contents of crude protein, fibre, and ash than that of the Yellow Globe mangold, whilst the Danish mangold occupied an intermediate position.

6. The yield of beet tops varied with the year, variety, and treatment. Yields ranged from 5·5 to 15·7 tons/acre.

7. The heavy nitrogenous top-dressing increased the output of dry matter from both beet and mangolds. The largest responses were from the root of the mangold and the tops of fodder-beet.

8. A starch equivalent of 13·0 and a protein equivalent of 0·7 has been calculated for fodder-beet with a dry-matter content of 21 per cent.

9. The advantages of fodder-beet, as compared with mangold, based on the four years' results, are discussed.

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SOIL AND MOISTURE CONSERVATION IN THE DRY REGIONS OF THE BOMBAY STATE

PART I. STUDIES IN SOIL CONSERVATION

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WITH PLATE 4

THE dry regions of the Bombay Deccan and Karnatak occupy a large proportion of the cultivated land which is characterized by scanty, ill-distributed and highly erosive rains, undulating topography, high wind-velocity, and shallow soil-depths in general. Ravages due to past erosion are widespread over the entire tract, and call for a sound policy of soil and moisture conservation. The Deccan (Northern Zone) of the dry tract is situated in the basaltic region known as the Deccan trap, and the Karnatak (Southern Zone) in regions of crystalline granites and gneisses, interspersed with sandstone, compacted shales, limestones, &c. (Fig. 1). The present land-forms in this tract are the results of age-long weathering and denudation, and consist of wide, open river-valleys with easy slopes all along. There are, however, from valley to valley, differences in the gradients of both the river-bed and the catchments on either flank, which give rise to a variegated pattern of soil formation and state of erosion in the two zones. Owing to the variation of this and other factors responsible for soil formation, classification based on 'phase' has been given prominence. In the Deccan (Northern Zone) the soils, mainly formed *in situ*, are invariably light to shallow, showing the influence of soil erosion on depth and distribution of soil. In the Karnatak (Southern Zone), where the soils are supposed to be of transported origin, the colour of the soil varies from deep black to limey brown according to the degree of erosion. Thus the soils of both zones could be classified on the basis of extent of soil erosion.

Climatically, the dry tract of this State is a part of the great 'Monsoon' area; failure of crops due to scanty rainfall or its ill-distribution is a regular feature. The period of heavy rains from August to October is known as the 'critical period of erosion'. Faulty land-use practices in the tract have been responsible for the present deterioration of the lands through soil erosion. The forest and pasture in this tract are both scanty and poor, and do not afford any protection to the soil against erosion. Further, these lands, which are predominantly under *rabi* (winter) crop cultivation, are loose, pulverized, and bare during the critical period of erosion, and therefore they suffer severe erosion owing to the beating actions of rains. This tract requires a carefully planned land-use programme based on survey and soil investigations for its proper development. Such investigations were started as early as 1933 at the Dry-Farming Research Station, Sholapur, which is situated in

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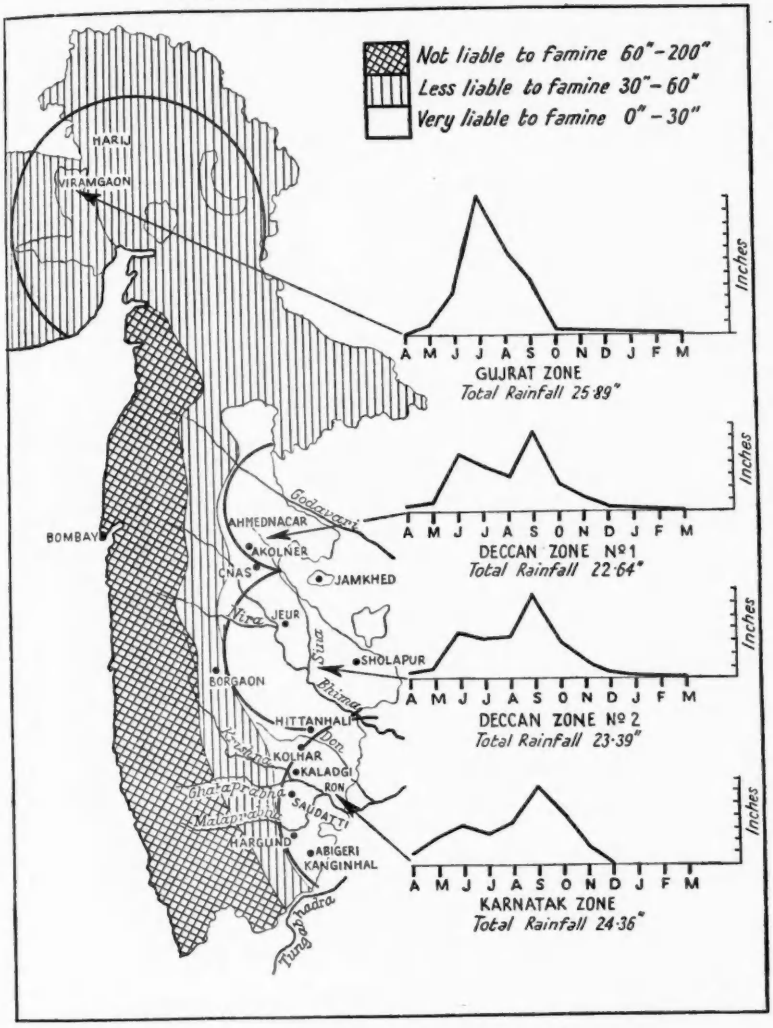

FIG. 1. Map of Bombay State showing scarcity zones.

the heart of the scarcity tract; their results up to date are described in this paper and further results will be published later.

Studies in Soil Erosion

Soil-erosion studies in India are of comparatively recent origin. No systematic quantitative measurements of run-off and erosion were made in India until the initiation of the co-ordinated Dry-Farming Schemes

in 1933 when a chain of research stations was established in Sholapur, in Bijapur (1936) and Hagari (1937), in the dry zones of Peninsular India. The salient features of experimental work on soil erosion, carried out in detail at the Sholapur Research Station will here be reviewed. The work consisted (*a*) of direct measurement of run-off and erosion, and (*b*) of indirect assessment of erosion in the tract by a systematic soil-erosion survey.

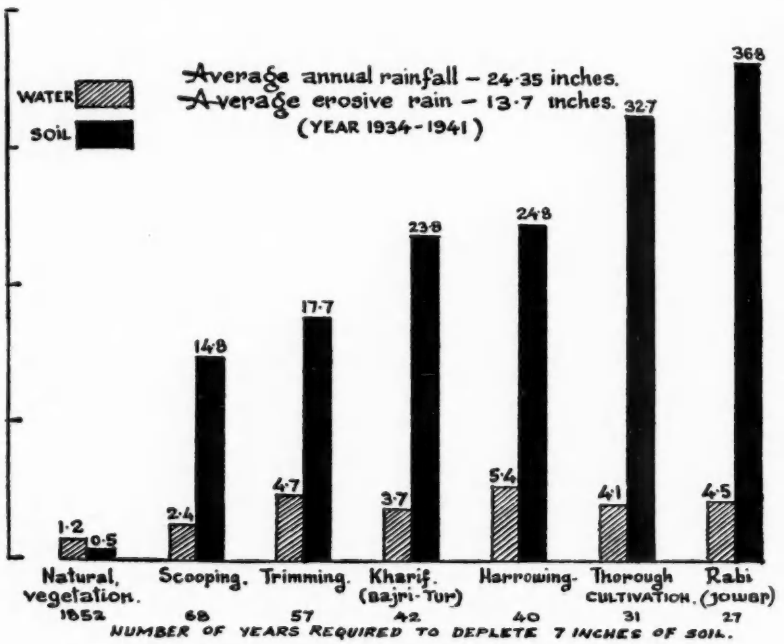

FIG. 2. Run-off of water in inches and erosion of soil in tons per acre.

Direct measurement.—The run-off plot technique adopted is of the type used by Duley and Miller in their classical experiments in the U.S.A. [1]. The plots were rectangular, 66 ft. by 8·25 ft., and occupied one-eighth of an acre. There were seven adjacent plots of these dimensions, the eighth having double the length. The average percentage slope of the plots was 1·18. The comparative results from the seven equal plots under different treatment is given in Fig. 2. The most striking feature is the extremely small loss of soil, 0·53 ton per acre, and the run-off, 1·15 in. out of 13·07 in. of erosive rains, suffered under nature vegetation (low-grade grasses and shrubs). By trimming the grasses, thus imitating over-grazing, the loss due to erosion and run-off increased to 17·7 tons per acre and 4·7 in. respectively. The influence of over-grazing can also be strikingly seen when the number of years

required to deplete 7 in. of top-soil is considered. In natural vegetation it takes 1,852 years to lose 7 in. of top-soil, whereas over-grazing removes the same depth in only 57 years. It is observed that shallow cultivation operations, e.g. harrowing, are less conducive to erosion than thorough cultivation; also that 'scooping' has considerably reduced the hazards of erosion and run-off. Comparative effects of *kharif* (monsoon) crop and *rabi* (winter) crop on run-off and erosion illustrate the advantage of having a vegetative cover during the rainy season. The cultivation of jowar (*Andropogon sorghum*), which is the common practice in this tract, shows an enormous loss of soil suffered by the land, viz. 7 in. of top-soil in 27 years, thus illustrating the gravity of the situation arising out of the present practice. Incidentally, it may be noted that the growing of legumes, particularly the spreading varieties of groundnuts, hulga (*Dolichos biflorus*), matki (*Phaseolus aconitifolius*), soya beans, and mug (*Phaseolus mungo*) is very effective in substantially reducing soil erosion and, to a certain extent, run-off. For these crops erosion losses vary from less than a ton to a little over 2 tons per acre.

Along with the losses of run-off water and soil considerable amounts of plant-nutrients are removed when the lands are put under cereal crops like jowar. This is illustrated in Table 1.

TABLE 1. *Losses of Plant-nutrients due to Erosion (lb. per acre)*

Constituents	*Natural vegetation*		*Cultivation of jowar*	
	Run-off	*Silt*	*Run-off*	*Silt*
N . . .	0·25	1·41	0·16	126·95
P_2O_5 . .	0·62	0·79	0·78	129·89
K_2O . .	..	7·79	..	1,273·3
CaO . .	31·83	27·76	44·42	8,521·1

The losses under natural vegetation are insignificant when compared with those under cereal cultivation. These losses occur every year over vast areas under *rabi*-cereal lands in this tract, which is estimated to cover 5·4 million acres. The total losses come to about 300,000 lb. both for nitrogen and phosphoric oxide, and over 3,000,000 lb. for potash. Such a stupendous drain cannot be fully made good even at great cost. The only solution is to resort to soil-conservation measures to check loss of soil, run-off, and plant-nutrients.

Divisor technique.—The set-up used in the previous experiment suffers from the handicaps of high cost of construction and maintenance, and difficulty in handling large volumes of water in their measurements and sampling technique, as also in estimating the rate of run-off and silt loss. To obviate these difficulties a simple type of run-off plot was tried. A duplicate set of rectangular plots measuring 33, 36, and 132 ft. long and 5·5 ft. broad was installed with a silt-trap and a divisor to collect only a known fraction of run-off in the collecting tank at the lower end of the plots (Plate 4, Fig. 3). The set-up, which is provided with

automatic discharge recorders (manufactured by Hindustan Clock Works, Poona, India), has been found less expensive yet capable of measuring run-off and silt more accurately. Before the introduction of the automatic recording devices, this set-up was worked at three research stations located in different soil-climatic zones of Deccan and Karnatak and has revealed interesting features of soil erosion conditioned by soil characteristics as shown in Table 2.

TABLE 2. *Rate of Soil Erosion in Controlled Plots, 1947–50*

Centre and percentage slope	*Average annual erosive rains (inches)*	*Average annual loss (tons per acre)*	*Average annual soil loss (tons per acre per inch of erosive rain)*
Akolner (1·7) .	11·27	2·70	0·24
Tembhurni (1·5) .	9·45	2·19	0·26
Kaladgi (1·7) .	7·77	6·51	0·85

The light-to-medium soils of the Deccan (Akolner and Tembhurni) are, on the average, erodible to the same extent, but the deep black soils of Karnatak (Kaladgi) appear to be about three times more erodible than those of the Deccan. This is borne out by the soil characteristics of these regions. The soils of the Deccan as a class are coarser and less retentive owing to their low clay-content, and they are also shallower in depth. On the other hand, the deep soils are clayey and highly retentive. These soils have a high dispersion coefficient, high exchangeable sodium, and low Ca/Mg and Ca/Na ratios, all indicative of the erosive character of these soils. Thus it appears that the problem of soil conservation of the deep black soil of Karnatak is entirely different from that of the Deccan soils. This has been borne out by the experience that the technique of anti-erosion measures useful in the light-to-medium soils of the Deccan has not proved successful in the Karnatak.

Splash technique.—Field studies to evaluate the efficiency of various crop-covers to control erosion were undertaken by using a splash apparatus [2] during the three years 1948–50. The maximum amount of splash takes place during August, September, and October. Crop-covers of groundnuts (*Arachis hypogea*), mug (*Phaseolus mungo*), Chavali (*Vigna catiang*), wal (*Dolichos lablab*), hulga (*Dolichos biflorus*), and matki (*Phaseolus aconitifolius*) with normal and five times normal seed-rates were tried at Sholapur. With average rainfall *Phaseolus aconitifolius* caused a splash of 53 gm. of soil, whilst *Dolichos lablab* gave the highest splash of 63 gm. According to the amount of splash, the crops studied were placed in the following descending order for efficiency of protecting the soil:

Phaseolus aconitifolius > *Dolichos biflorus* > *Vigna catiang* > *Phaseolus mungo* > *Arachis hypogea* > *Dolichos lablab.*

Efficiency in preventing the impact of falling rain-drops can further be improved by increasing the seed-rates of the cover-crops. The

increase of seed-rates of *Phaseolus aconitifolius* and *Dolichos biflorus* to five times the normal reduced soil-splash to 45 and 48 gm. respectively.

Rainfall simulation.—It is difficult to isolate the effect of individual factors contributing towards soil erosion under field conditions. To assess the performance of these factors separately a new line of investigation has recently been initiated by the erection of a rainfall-simulator to work under controlled semi-laboratory conditions. It consists of testing bulked soil samples in trays under different slopes for their susceptibility to erosion when subjected to various intensities of rainfall. The device has been recently standardized for work on soils from different localities. It is proposed to correlate the data obtained with data from field studies and soil analyses, and particularly with soil properties influencing erosion.

Catchment studies by standing-wave flume.—The small-plot technique under controlled conditions, though useful in the preliminary studies of soil erosion, has indicated that for a further and fuller understanding of this intricate phenomenon it is necessary to measure run-off and erosion from self-defended catchments of varying size, shape, slope, and field practices. Standing-wave flume set-ups with discharge-recording devices are being installed at some places in the terraced fields to measure run-off and erosion of known area, slope, and crop-cover. The data of these experiments would lead to the determination of characteristics of erosion for planning suitable control measures.

Soil-erosion survey.—A systematic soil-erosion survey was undertaken for the first time in 1945 to assess the extent, nature, and severity of erosion in the scarcity tract of the Bombay Deccan and Karnatak. The technique followed was based on random selection of complete catchment units from 500 to 2,000 acres, distributed over the scarcity districts of Ahmednagar, Sholapur, Bijapur, and eastern portions of the districts of Satara, Poona, Belgaum, and Dharwar. The survey was conducted in 43 centres, of which 22 lie in the Deccan and the remaining 21 in the Karnatak. The total acreage covered was 80,541 acres.

The technique of survey consists of field observation of soil profile, depth, colour, surface conditions, and percentage slope, supplemented by information about land-use practices and soil valuation. The soil samples were drawn from the profile by forming a regular grid pattern, and analysed. The degree of erosion has been estimated on the basis of soil groups explained earlier in which the normal profile on the ridge is taken as a standard for comparison. The summary of results obtained is given in Table 3.

The tabulated data yield a fair estimate of the conditions of soil erosion obtaining in the scarcity tract. The percentage areas left in the slightly eroded state are only 17 and 20 in the Deccan and Karnatak respectively, whereas 69 and 73 per cent. of the land consists of moderately and highly eroded soils [3]. These results, together with those of the run-off plots at the Research Station, bring home very clearly the fact that within a few generations we may be left with very little land for raising good farm crops under dry conditions if we continue to neglect our soils [4]. A recent assessment of agricultural lands of Madhya Pradesh,

India, after 75 years also shows glaringly the havoc done by erosion where most of the medium-deep and medium soils are now converted into shallow soils [5]. In conclusion it may be said that the gravity of the situation strongly emphasizes the urgent need to find suitable anti-erosion measures by carefully planned research work.

TABLE 3. *Nature and Extent (in acres) of Soil Erosion in Different Zones of Scarcity Tract*

Zone	*No. of centres*	*Uneroded or slightly eroded soils*	*Moderately eroded soils*	*Highly eroded soils*	*Accumulated soils*	*Total*
Deccan .	22	6,862 (17)	12,236 (31)	15,324 (38)	5,811 (14)	40,233
Karnatak .	21	7,956 (20)	18,916 (47)	10,641 (26)	2,795 (7)	40,308
	43	14,818	31,152	25,965	8,606	80,541

The figures in brackets indicate percentages of the total surveyed area.

Summary

The results of investigations carried out on soil and moisture conservation in the dry regions of the Bombay State, India, have been broadly reviewed.

The experimental work described consists in the direct measurement of run-off and erosion, and indirect assessment of erosion by systematic soil-erosion survey. Erosion measurements in the run-off plots indicate high losses of soil under cereal cropping (24–37 tons of soil per acre per annum) as against less than 2 tons per acre per annum for spreading varieties of legumes. An estimate of the losses of nitrogen and phosphoric oxide over 5·4 million acres of winter-cereal crops shows that about 300,000 lb. of these constituents are lost annually. A random erosion survey conducted over 80,000 acres of cultivated area in the scarcity tract reveals that 69–73 per cent. of the total area has been severely eroded in the Deccan and Karnatak zones respectively. When this result is considered in context with the experimental data, the gravity of the present situation and its future consequences on the agriculture of this region emphasizes the urgency of investigations on anti-erosion measures.

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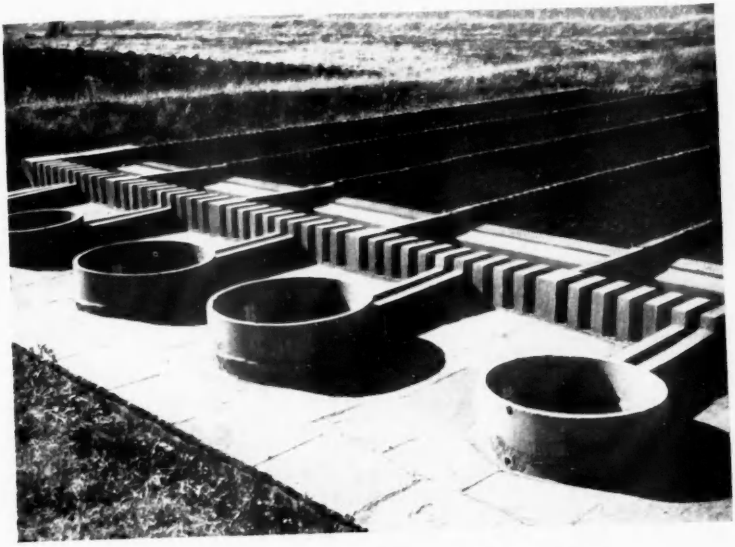

FIG. 3. The devisor set-up for run-off measurements

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